ANNUAL RESEARCH REPORT
U.S. WATER CONSERVATION LABORATORY

1996

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ANNUAL RESEARCH REPORT

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U.S. WATER CONSERVATION LABORATORY
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INTRODUCTION

The U. S. Water Conservation Laboratory (USWCL) Annual Research Report is intended to describe progress on our research projects in 1996 and plans for 1997 and beyond. Our targeted reading audience includes upper level management within the Agricultural Research Service, other ARS research locations and entities involved in natural resources research, and our many collaborators and cooperators. It is our intent to keep the individual reports short but informative, focusing on what is being done and why, the problem, objectives, approach, brief results, future plans, and cooperators involved in each program. We want to make sure that the product of the research and its contribution to water conservation are clear to all.

Efforts to identify and interact with users and to inform the public are part of an overall USWCL outreach program. In the January 1996 Review and Planning meeting, we took another step in an intensified effort over the past two years to identify our clients, inform them, and benefit from their insights. The intent is to create early collaboration that will help focus our programs and contribute to technology transfer and use. Some of the invitees were identified for their special interest in specific research programs ("targeted" users), while others were invited for their overall interest in USWCL research. Each of the five CRISs had at least one targeted user participant. In all, 25 outside participants attended, representing private organizations, universities, U. S. congressional offices, and federal, state, and county agencies. An even larger number of "targeted" users will attend the January 1997 Review and Planning meeting as we move toward more permanent/continuing interaction with users. Activities to inform the public over recent months have included the annual Science and Engineering Expo hosted for area high school science classes; a general open house; and exhibits at a state-wide Environmental Education Resource Fair and Arizona Agricultural Day observance, both of which drew large numbers of people. Other outreach activities have included a mini open house, an on-site presentation for two local schools, and an exhibit at the Arizona Agriculture Institute. These types of activities, along with the Annual Research Report, all provide opportunities for us to tell our research story and to assess and make our program more responsive to identified needs. The U. S. Water Conservation Laboratory homepage is on the internet (**www.uswcl.ars.ag.gov/uswcl.htm**) and under continuing development, all part of informing the public and improving communications. I invite you to visit.

As a policy, we strive to leverage our available base funding into well-targeted, broader-based programs by attracting outside resources. We are committed to working collaboratively with other agencies and industry in bringing post doctorates, visiting scientists and engineers, graduate students, and persons on sabbaticals to the USWCL to maintain or expand our research programs. Outside resources are instrumental in our continued work in major program areas. In-kind human resources provided by many of our cooperators and collaborators are highly significant and enhance our programs, especially by each individual's stimulating effects on our research efforts (please refer to the list of Cooperators shown at the end of each report and summarized on pages viii through x). To the USWCL overall, this outside funding represents an estimated 15% of our FY97 total budget, but more important, it amounts to over 60% of our discretionary dollars.

I invite you to read and use this Annual Research Report. The research staff's telephone, fax, and e-mail numbers are on page v). Let us know if there are questions or comments, either from a technical research standpoint or about ideas you might have regarding communication with our clients; all are invited and will be appreciated.

Allen R. Dedrick, Director

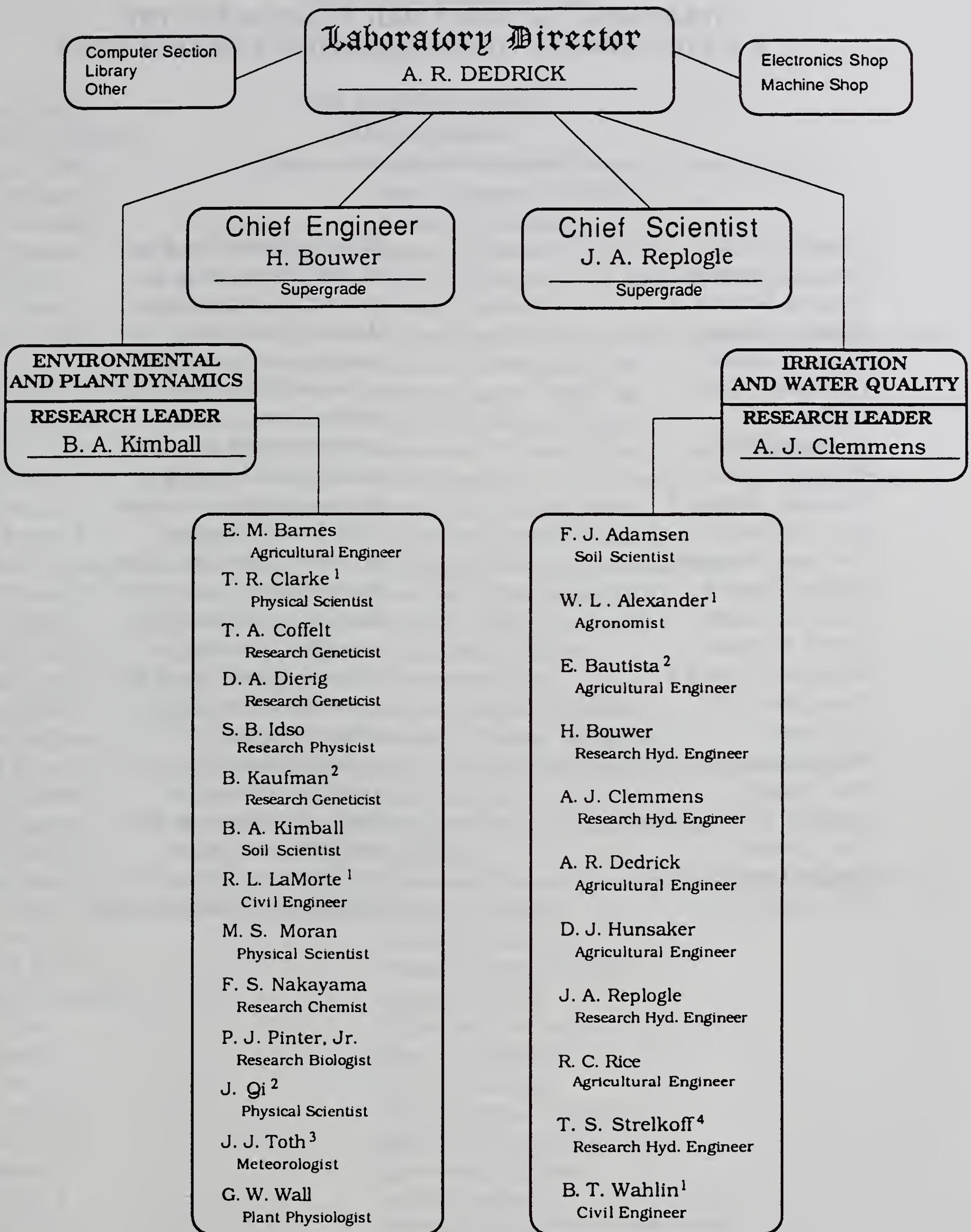
U. S. WATER CONSERVATION LABORATORY
ORGANIZATIONAL DESCRIPTION AND MISSION STATEMENTS

The mission of the U. S. Water Conservation Laboratory (USWCL) is to conserve water and protect water quality in systems involving soil, aquifers, plants, and the atmosphere. Research thrusts involve developing more efficient irrigation systems, improving the management of irrigation systems, developing better methods for scheduling irrigations, developing the use of remote sensing techniques and technology, protecting groundwater from agricultural chemicals, commercializing new industrial crops, and predicting the effect of future increases of atmospheric CO_2 on climate and yields and water requirements of agricultural crops.

The U. S. Water Conservation Laboratory research program is organized under two Research Units: Irrigation and Water Quality (I&WQ) and Environmental and Plant Dynamics (E&PD). I&WQ focuses on water management with emphasis on irrigation and water quality; E&PD concentrates on carbon dioxide-climate change, germplasm development for new crops, and remote sensing. Drs. Albert J. Clemmens and Bruce A. Kimball are the Research Leaders for the respective Research Units. The organizational structure for the USWCL is shown in figure 1, and the entire USWCL personnel list in table 1.

The mission of the Irrigation and Water Quality Research Unit is to resolve water management problems for irrigated agriculture through research aimed at conserving and augmenting water supplies. Goals are to develop management strategies and tools for the effective use of water and fertilizers in irrigated agriculture, develop tools for the protection of groundwater supplies from degradation as the result of agricultural practices, develop technologies for safe reuse of municipal wastewater, and transfer these results to practice through technology transfer efforts. The unit focuses on identifying individual actions and practices for resolving water supply and quality issues at the farm and project levels, and the various inherent interrelationships.

The mission of the Environmental and Plant Dynamics Research Unit is to develop optimum resource management strategies for meeting national agricultural product requirements within the context of global change. Goals are to predict increased CO_2 and global climate change effects on plant growth and water use; develop new crops to meet national needs for renewable, agriculturally-based products; develop remote sensing techniques for farm management and wide-area evapotranspiration estimation. CO_2-climate research will furnish a knowledge base and models to assess global change impact on future agriculture, increasing the security of the world's food supply and benefitting all consumers. New Crops will contribute to the diversification of American agriculture while producing renewable sources of raw materials such as non-allergenic latex (medical products), hydroxy fatty acids (cosmetics and lubricants), and low pollutant epoxy fatty acids (paints and coatings). Remote Sensing research will benefit growers and consumers by improving farm management decisions and the accuracy of water resource assessments.



[1] Category 3 scientist
[2] Post-Doctoral Research Associate
[3] Post-Doctoral Research Associate (shared 50%/50% by US Water Cons. Lab., Phoenix, and Southwest Watershed Research, Tucson.)
[4] Research Professor, University of Arizona

Figure 1. U. S. Water Conservation Laboratory Organization, September 30, 1996

TELEPHONE, FAX, AND E-MAIL NUMBERS FOR THE U. S. WATER CONSERVATION LABORATORY RESEARCH STAFF

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Toth, James J.	toth@tucson.ars.ag.gov
Wahlin, Brian T.	bwahlin@uswcl.ars.ag.gov
Wall, Gerard W.	gwall@water1.uswcl.ars.ag.gov

Table 1. U. S. Water Conservation Laboratory Staff, September 30, 1996

PERMANENT EMPLOYEES

Name	Title
Adamsen, Floyd J.	Soil Scientist
Alexander, William L.	Agronomist
Arterberry, Carl A.	Agricultural Science Research Technician/Soils
Askins, JoAnne	Physical Science Technician
Barnes, Edward M.	Agricultural Engineer
Bouwer, Herman	Research Hydraulic Engineer
Brown, Rita C.	Office Automation Assistant (Transferred 9/22/96)
Clarke, Thomas R.	Physical Scientist
Clemmens, Albert J.	Research Leader and Supervisory Research Hydraulic Engineer
Coffelt, Terry A.	Research Geneticist (Plants)
Colbert, Sharette N.	Physical Science Technician
Corris, Virginia D.	Office Automation Assistant
Dahlquist, Gail H.	Agricultural Science Research Technician/Plants
Dedrick, Allen R.	Laboratory Director and Supervisory Agricultural Engineer
Dierig, David A.	Research Geneticist (Plants)
Gerard, Robert J.	Laboratory Support Worker
Gerszewski, Susette M.	Biological Science Technician/Plants
Harner, Paulina A.	Secretary (Office Automation)
Heckart, Donna J.	Secretary (Office Automation)
Hunsaker, Douglas J.	Agricultural Engineer
Idso, Sherwood B.	Research Physicist
Johnson, Kathy J.	Physical Science Technician
Johnson, Stephanie M.	Biological Science Technician
Kimball, Bruce A.	Research Leader and Supervisory Soil Scientist
LaMorte, Robert L.	Civil Engineer
Leake, Gregory S.	Biological Science Technician/Plants
Lewis, Clarence L.	Machinist
Martinez, Juan M.R.	Agricultural Science Research Tech/Soils (Retired 9/02/96)
Mastin, Harold L.	Computer Assistant
Mills, Terry A.	Computer Specialist
Moran, M. Susan	Research Physical Scientist
Nakayama, Francis S.	Research Chemist
Padilla, John	Engineering Technician
Pettit, Dean E.	Electronics Engineer
Pinter, Paul J., Jr.	Research Biologist
Powers, Donald E	Physical Science Technician
Replogle, John A.	Research Hydraulic Engineer
Rice, Robert J.	Agricultural Engineer
Rish, Shirley A.	Program Analyst
Rokey, Ric R.	Biological Science Technician/Plants
Salisbury, T. Lou	Secretary (Office Automation)
Seay, L. Susan	Publications Clerk (Office Automation)
Seay, Ronald S.	Agricultural Science Research Technician
Strand, Robert J.	Engineering Technician
Vinyard, Stephen H.	Physical Science Technician
Wahlin, Brian T.	Civil Engineer
Wall, Gerard W.	Plant Physiologist

TEMPORARY EMPLOYEES

Name	Title
Bautista, Eduardo	Agricultural Engineer
Bhattacharya, Nick	Collaborator
Bross, Monique	Physical Science Technician
Draper, Karilee	Clerical Volunteer
Eshelman, Trathford	Physical Science Technician (Resigned 8/16/96)
Farrugia, Carmen	Physical Science Technician (Transferred 9/30/96)
Holifield, Chandra D.	Biological Technician
Kaiser, Aaron R.	Biological Science Aid
Kaufman, Benjamin	Research Geneticist/Plants
Lauver, Lisa M.	Biological Science Aid (Resigned 8/23/96)
Mitchell, Thomas A.	Engineering Technician
Olivieri, Laura M.	Biological Science Technician
Qi, Jiaguo	Physical Scientist
Rebman, Jon P.	Biological Science Technician/Plants (Resigned 3/02/96)
Renteria, Francisca Y.	Custodial Worker (Resigned 10/11/96)
Richards, Stacy E.	Biological Science Aid
Salywon, Andrew M.	Biological Sience Technican/Plants
Thompson, Anson E.	Collaborator (Deceased 6/14/96)
Tomasi, Belinda A.	Physical Science Technician
Toth, James J.	Meteorologist
West, Kathy S.	Biological Science Technician

TEMPORARY STATE EMPLOYEES

Baker, Michael G.	Research Specialist-Staff
Brooks, Talbot J.	Research Technician
Dai, Feixiao	Research Assistant
Lewis, Laurie A.	Senior Machinist/Staff
McCurdy, Charles	General Maintenance Mechanic
Novak, Patricia L.	Research Assistant/FACE (Resigned 8/25/96)
O'Brien, Carrie C.	Research Laboratory Assistant-Staff
Pabian, David J.	Associate Engineer/FACE
Schmidt, Baron V.	Computer Programmer Assistant
Slosky, Edward J.	Engineering Technician (Resigned 5/19/96)
Strelkoff, Fedja	Research Hydraulic Engineer/Research Professor (UofA)
Tomasi, Pernell M.	Research Laboratory Assistant

U. S. WATER CONSERVATION LABORATORY
COOPERATORS during 1996

INSTITUTION	CITY/COUNTRY/STATE
Universities	
Arizona State University	Tempe, Arizona
California Polytechnic State University	San Luis Obispo, California
Colorado State University	Fort Collins, Colorado
Delft Technical University	Delft, The Netherlands
Free University of Amsterdam	The Netherlands
Harvard University	Cambridge, Massachusetts
Humbolt University	Berlin, Germany
Oregon State University	Corvallis/Medford, Oregon
Rutgers University	New Brunswick, New Jersey
Texas A&M University	Fort Stockton/College Station, Texas
Virginia State University	Petersburg, Virginia
University of Akron, Department of Polymer Science	Akron, Ohio
University of Alberta	Edmonton, Alberta, Canada
University of Arizona -	Tucson, Arizona
College of Agriculture	
Cooperative Extension	
Dept of Plant Sciences	
Dept of Soil & Water Science	
Dept of Hydrology & Water Science	
Dept of Agric & Biosystems Engineering	
Office of Arid Land Studies	
Maricopa Agricultural Center	Maricopa, Arizona
University of California, Botany & Plant Sciences	Riverside, California
Universitat Autonoma	Barcelona, Spain
Universita della Tuscia	Viterbo, Italy
University of Essex	Colchester, United Kingdom
University of Florida	Gainesville, Florida
University of Georgia	Athens, Georgia
University of Guelph	Guelph, Ontario, Canada
University of Idaho	Moscow, Idaho
University of North Dakota	Fargo, North Dakota
University of Wisconsin	Madison, Wisconsin
University of Michigan	Ann Arbor, Michigan
Utah State University, Dept. of Biological & Irrig. Engrg.	Logan, Utah
Federal Agencies	
Farm Service Agency	Casa Grande, Arizona
U. S. Bureau of Reclamation	
Hydraulics Laboratory	Denver, Colorado
Lower Colorado Region	Boulder City, Nevada
Phoenix Area Office	Phoenix, Arizona
USDA, Natural Resources Conservation Service	Phoenix/Casa Grande, Arizona
	Dexter, Missouri
National Water and Climate Center	Portland, Oregon
USDA, Agricultural Research Service	
Carl Hayden Bee Research Laboratory	Tucson, Arizona
Conservation and Production Research Laboratory	Bushland, Texas
Foreign Disease-Weed Science Research	Frederick, Maryland

Grassland Protection Research	Temple, Texas
Great Plains Systems Research	Ft. Collins, Colorado
Hydrology Laboratory	Beltsville, Maryland
National Center for Agricultural Utilization Research	Peoria, Illinois
National Program Staff	Beltsville, Maryland
National Soil Dynamics Laboratory	Auburn, Alabama
National Agricultural Water Quality Laboratory	Durant, Oklahoma
North Central Plant Introduction Station	Ames, Iowa
Soil & Plant Research	Fort Collins, Colorado
Soil/Water Conservation Research	Lincoln, Nebraska
Southwest Watershed Research Center	Tucson, Arizona
Subtropical Agricultural Resarch Laboratory	Weslaco, Texas
Tropical Crops & Germplasm Research	Mayaguez, Puerto Rico
U.S. Salinity Laboratory	Riverside, California
Water Management Research	Ft. Collins, Colorado
Western Cotton Research Laboratory	Phoenix, Arizona
Western Integrated Cropping Systems Research	Shafter, California
Western Regional Research Center	Albany, California
Western Wheat Quality Laboratory	Pullman, Washington
USDA-CSREES, Office of Agricultural Materials	Washington, DC
U.S. Department of Energy	Washington, DC
Atmospheric & Climate Research Division	
Office of Health and Environmental Research	
USDI-U.S. Geological Survey	Santee, California
	Sacramento, California

State Agencies

Arizona Department of Agriculture	Phoenix, Arizona
Arizona Department of Environmental Quality	Phoenix/Tucson, Arizona
Arizona Department of Water Resources	Phoenix, Arizona
Phoenix Active Management Area	Phoenix, Arizona
Pinal Active Management Area	Casa Grande, Arizona
California Department of Water Resources	Sacramento, California
Irrigation Management Service	Casa Grande, Arizona
West Pinal Natural Resource Conservation District	Casa Grande, Arizona

Other

Agrigenetics	Madison, Wisconsin
Automata, Inc.	Grass Valley, California
Biosphere 2	Oracle, Arizona
Brookhaven National Laboratory	Upton, Long Island, New York
Buckeye-Roosevelt Natural Resources Conservation District	Buckeye, Arizona
CEMAGREF-Irrigation Division	Montpellier, France
Center for Irrigation Technology	Fresno, California
Central Arizona Irrigation & Drainage District	Eloy, Arizona
Central Arizona Water Conservation District	Phoenix, Arizona
Centre' d' Etudes Spatiales de la BIOspere	Toulouse, France
Coachella Valley Resource Conservation District	Indio, California
Electric Power Research Institute	Palo Alto, California
Gila River Farms	Pinal County, Arizona
CESBIO, CNES	France
GEOFLOW	San Francisco, California
GERSAR-SCP, Societedu Canal du Provence	Aix-en Provence, France
Global Water	Fair Oaks, California
Goddard Space Flight Center, NASA	Greenbelt, Maryland

Hunter Industries	San Marcos, California
Imperial Irrigation & Drainage District	Imperial, California
Institute of Geodesy and Cartography	Warsaw, Poland
Instituto de Agricultura Sostenible	Cordoba, Spain
International Flora Technologies	Gilbert, Arizona
Irrigation Association	Fairfax, Virginia
Irrometer Company	Riverside, California
Lawrence Livermore National Laboratory	Livermore, California
Maricopa Stanfield Irrigation & Drainage District	Stanfield, Arizona
Mexican Institute of Water Technology	Cuernavaca, Mexico
Mycogen, Plant Sciences	Madison, Wisconsin/San Diego, California
National Institute of Agro-Environmental Sciences	Tsukuba, Japan
Natural Heritage Division	Nashville, Tennessee
Nelson Irrigation	Walla Walla, Washington
Nu Way Flume & Equipment Company	Raymond, Colorado
Plasti-Fab	Tualatin, Oregon
Potsdam Institute for Climate Impact Research	Potsdam, Germany
Salt River Project	Phoenix, Arizona
Superior Council for Scientific Research (CSIC, AULA DEI)	Zaragoza, Spain
TRACOR, GIE	Provo, Utah
Valmont Industries	Valley, Nebraska
Wellton-Mohawk Irrigation & Drainage District	Wellton, Arizona
Western Integrated Cropping Systems Research	Shafter, California

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INTEGRATED IRRIGATION SYSTEM WATER MANAGEMENT

MANAGEMENT IMPROVEMENT PROGRAM (MIP) FOR IRRIGATED AGRICULTURE

A. R. Dedrick, Supervisory Agricultural Engineer; E. Bautista, Agricultural Engineer;
S. A. Rish, Program Analyst; and A. J. Clemmens, Supervisory Research Hydraulic Engineer

PROBLEM: Enhanced long-term management of water and other natural resources, grower profitability, and overall social well-being are essential to a sustainable irrigated agriculture. Because approaches to these objectives are often uncoordinated, all agricultural stakeholders--farmers, irrigation districts, other support and regulatory organizations, and other interested parties--need to interact proactively to address these needs. To this end, the Management Improvement Program (fig. 1 depicts the three-phased MIP process), a management process similar to those used to improve the performance of corporate organizations, was applied to the business of irrigated agriculture. The purposes of this research are 1) to develop, apply, and refine for future use the MIP methodology; and 2) to establish conditions in the MIP application area for the continued improvement of farming practices and support services provided to farms by the district and other irrigation-related agencies while conserving related resources.

APPROACH: In December 1990, under the direction of the U. S. Water Conservation Laboratory (USWCL), an Interagency Management Improvement Program (IMIP) was initiated by six agencies[1] interested in the potential of the MIP to support improved irrigated agricultural productivity, profitability, and natural resource management. From April 1991 to January 1994, a demonstration project was carried out in the Maricopa-Stanfield Irrigation and Drainage District (MSIDD) in central Arizona (fig. 2 is a schematic representation of participating entities). In January 1994, the MIP Team[2] ended its formal leadership of the Demonstration MIP, and a local, grower-led, grower-interagency MSIDD MIP Coordinating Group (CG) assumed ongoing responsibility for future MIP initiatives in the MSIDD area. A formal evaluation of the MSIDD-Area MIP was completed and the report published in October 1994. Following are key events and activities during 1996. (See "Annual Research Reports," 1991 through 1995, for earlier MIP milestones.
1) MSIDD MIP Coordinating Group (CG) Program Review and Planning Meeting. In February 1996, the MIP Team conducted a program review and planning meeting requested by the MSIDD MIP CG. Attendees included CG members (MSIDD-area growers and representatives of USBR, NRCS, FSA, ADWR, CAWCD, West Pinal Natural Resources Conservation District, Cooperative Extension, and MSIDD), former CG members, and other invitees. Cooperative Extension participated in the meeting as a new CG member.
2) Potential Reapplication of the MIP. Discussions begun in 1995 relative to an MIP application in an irrigation district in Texas have been renewed at the request of USBR.
3) Publications and Presentations. a) A grower and representatives of USBR, NRCS, MSIDD and ADWR, along with ARS-USWCL, presented a session on the MIP at the ASCE North American Water and Environment Congress '96 in Anaheim, California. The presenters authored or co-authored papers, which will appear in the conference proceedings. b) An invitation was received from the Environmental and Energy Study Institute (EESI)[3] in Washington, DC, for a panel of MSIDD MIP participants to take part in a forum on the Federal role in providing research and technical assistance to water users. The timing, September 1996, was not opportune,

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[1] These agencies are USDA-ARS and -N RCS; USDI-USBR; AZ Depts. of Water Resources and Environmental Quality; and The Univ. of AZ Cooperative Extension. They, along with the AZ Dept. of Agriculture and The University of AZ College of Agriculture who joined later, comprise the general oversight IMIP Coordinating Group.

[2] The demonstration project MIP Team included Dedrick, Bautista, and Rish of the USWCL; and consultants W. Clyma (MIP Specialist) and D. B. Levine (Management/Team-Building Specialist). The MIP Team provided overall management of the demonstration activities, which included the direct development and facilitation of MIP events. In addition, the Team maintained ongoing communication with participants, addressed concerns and problems as they arose, and was responsible for the development and publication of MIP-related documents.

[3] EESI is a nonprofit organization that provides information and briefings to Congress and other national policy makers in the interest of environmentally sustainable societies.

so EESI will try to reschedule the panel for spring 1997. c) A sidebar on the MSIDD MIP CG was included in a recently released National Research Council Water Science and Technology Board study report, *A New Era in Irrigation.* d) Five papers for a technical journal series are in various draft stages.

FINDINGS: At their February 1996 program review and planning meeting, the MSIDD MIP CG reviewed and adjusted their overall strategic approach, their program array and priorities (table 1), and the related operational structures and procedures. The meeting provided an appropriate transition of CG leadership from the first grower-leader, Gary Butler, to the new grower-leader, Karen Ollerton. Now in its third year, the CG continues to publish a newsletter and sponsor town-hall and grower-to-grower meetings. The addition of Cooperative Extension representation on the CG is providing needed expertise for grower support and strengthening the CG organizationally.

As noted above under "Papers and Presentations," MSIDD-Area MIP participants continued to be a source of insights and information about the MIP experience. Some participants are also co-authoring papers for a journal series documenting the Demonstration MIP.

The holistic nature of the MIP in considering systemically the farm and the entities that impact it was a new approach to making and managing change in irrigated agriculture in the U. S.[4] As we continue to have exchanges with farmers and others in agriculture-related fields about the need for change and how change traditionally is brought about, certain aspects of the MIP approach gain greater clarity. In particular, the interdisciplinary (including technical, social,-economic) understanding resulting from the Diagnostic Analysis of the level of performance of irrigated agriculture in the area and the causes of both high and low performance provide a foundation for making change that is not found in other change processes. All too often, projects undertaken without this understanding fail because critical aspects of problems are not considered; e.g., social and cultural constraints or lack of support expertise, which undermine successful management and use of new technologies. Among potential problems, there is a risk that action undertaken without this kind of understanding will address symptoms rather than causes.

INTERPRETATION: The seriousness with which the MSIDD MIP Coordinating Group undertook their tasks at the February program review and planning meeting, in areas relating to program planning, organizational development, and institutionalization, reflects commitment to their unique role of providing a focused, coordinated means to address the needs of the area's irrigated agriculture. In preparatory meetings with CG agency members prior to the review meeting, the importance of grower involvement in the CG was repeatedly emphasized by the agencies. Clearly, they view the central position of the growers in the diagram of participating organizations (fig. 2) as very real as well as an appropriate focus symbol.

With regard to technology transfer effected by the MIP, it is important to note that the MIP has two managerial and technology transfer components; first, a large part of the impact of an MIP in a targeted area is associated with how successfully appropriate technology and managerial changes are made in the area, the success of which depends on the individual MIP; the second is the transference of the MIP methodology itself to potential users, much of which still remains to be done.

FUTURE PLANS: Work will focus on (1) documentation of the Demonstration MIP, including completion of a paper series for a special issue of *Irrigation and Drainage Systems Journal*; (2) preparation of a manual to guide future MIP applications in other agricultural settings; (3) exploration of appropriate reapplication of the MIP model, including an application in the irrigation district in Texas; and (4) assessment of alternative scenarios for MIP institutionalization.

COOPERATORS: Cooperators include entities in figure 2, plus Colorado State University. Funding has been provided by ARS, USBR, NRCS, and ADWR; with significant in-kind contributions by all involved.

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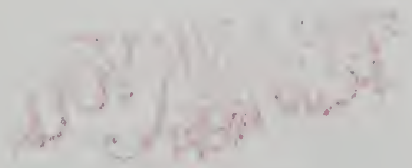
[4] Parts of the MIP had been applied overseas.



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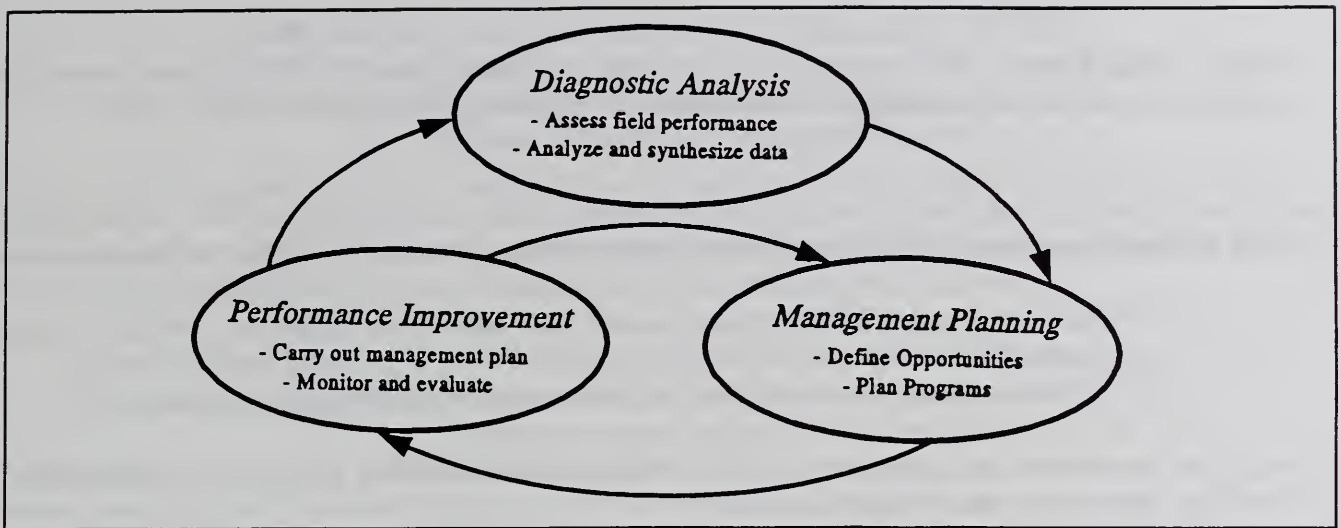

Figure 1. The three phases of the Management Improvement Program feed into one another. Diagnostic analysis yields an interdisciplinary understanding of the performance of irrigated agriculture in the area. Management Planning results in a shared understanding of the performance among growers and participating organizations as well as identification of opportunities for improvement and jointly developed plans for managerial and technological changes to address those opportunities. Performance Improvement results in implementation of the plans and establishment of long-term, self-supporting mechanisms to sustain the effort after the formal end of the MIP.

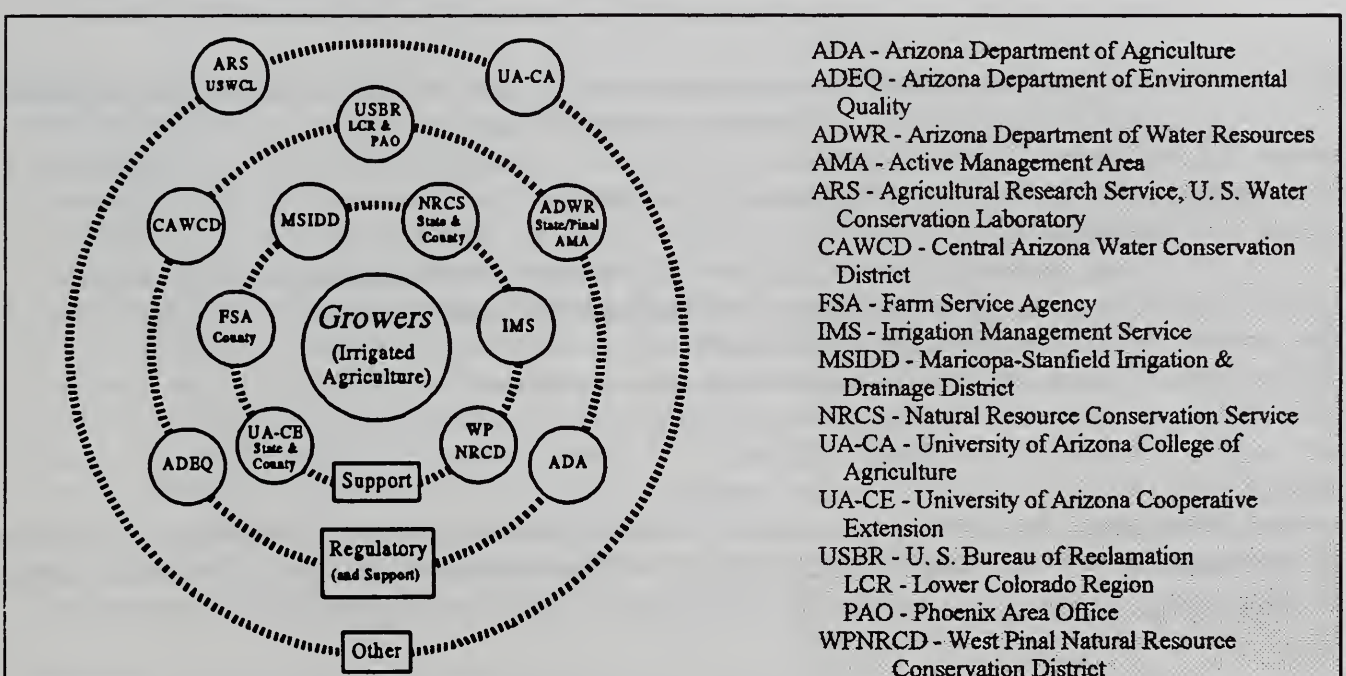

Figure 2. Schematic representation of entities involved in irrigated agriculture in the MSIDD-Area. Entities were included as participants because of their potential to impact irrigated agriculture in the area. Improved profitability and sustainability of irrigated agriculture (along with improved natural resource management) were the goals of the Demonstration MIP; therefore, growers, the main focus of the program, are shown appropriately in the center. Moving outward from the growers, the first circle connects organizations or entities directly supporting agriculture in the MSIDD area; the second connects organizations with primarily regulatory missions although they may also have some support functions; and the furthest circle includes the two research and/or educational organizations involved.

Table 1. At their February 1996 Program Review and Planning Meeting, the MSIDD MIP Coordinating Group identified and categorized improvement opportunities for irrigated agriculture in the MSIDD area:

- The following were identified as performance areas continuing to provide opportunities for improvement:
  - The variability on MSIDD-area farms in such practices as water application, fertilizer usage, and tillage operations;
  - Gaps between the potential and actual performance of on-farm irrigation systems;
  - The reach and effectiveness of agency support programs;
  - Area-wide communications between entities and growers, among growers, and among entities;
  - Need for commodity diversification.

- While there remain significant continuing opportunities, performance in the following areas was seen as improved since the start of the MIP in 1991:
  - The District's water delivery service and its stance towards growers;
  - Area-wide communications;
  - Costs to growers for water and assessments;
  - Use of crop rotation, particularly the planting of winter grains.

- The following were identified as performance areas currently of high priority, and for which the CG might try to identify and support improvement opportunities:
  - Assuring long-term, affordable water availability;
  - Pest control;
  - Timely technology transfer, e.g., for yield estimation and related management decisions;
  - Financing, in particular in relationship to water and pest control costs;
  - Support for commodity diversification;
  - Continued improvements to area-wide communications.

Three work groups were formed as a starting point to pursue improvement opportunities: 1) Program Coordination, Monitoring, and Guidance; 2) MSIDD Area-Wide Information Sharing; and 3) External Linkages.

IRRIGATION INDUSTRY-ARS COLLABORATIVE EFFORT[1]

A. R. Dedrick, Supervisory Agricultural Engineer; and
D. F. Heermann, Supervisory Agricultural Engineer

PROBLEM: The "Irrigation Industry-ARS Collaborative Effort," was initiated in 1991, led by Dedrick and Heermann, to promote a concerted, sustained effort to impact irrigation on a broad scale up through the national level. It aimed to address issues facing irrigation as a whole, with its stated purpose

> "for the Irrigation Industry and the Agricultural Research Service to foster and focus an ongoing partnership in support of irrigation that yields optimal societal benefit."

APPROACH: In May 1991, a workshop with over 40 attendees, almost evenly divided between the Irrigation Industry and ARS irrigation and drainage researchers, met to launch the effort. At that meeting, a Leadership Group (see table 1 for current Leadership Group members) was mandated to lead the Collaborative Effort. Over the last five years, the Leadership Group has guided actions to address the agenda that emerged from the workshop, including meetings to adjust overall Collaborative Effort plans and to review and support its workgroup activities focused on three main thrusts:

- Supporting the Irrigation Association (IA) as a key representative of the Irrigation Industry in identifying priority irrigation related research needs and communicating them to the research community,
- Increasing the amount of collaborative research carried out by Irrigation Industry and ARS scientists and engineers, and
- Proposing and supporting a study by the Water and Science Technology Board (WSTB) of the National Academy of Sciences-National Research Council focusing on the future of irrigation in the U. S.

FINDINGS: Key results of the Collaborative Effort over the last year include the following (see 1993 through 1995 USWCL "Annual Research Reports" for previous findings):

- <u>Identification of Priority Research Needs</u>. The IA Board of Directors formally established a Research Committee in 1994. The present Committee chair, Rudy Unruh of Valmont Industries, Inc., with input from committee members, has prioritized the list of research needs identified by the industry for further consideration by the Committee at its November 1996 meeting.[2]
- <u>Increasing the Amount of Collaborative Research Carried out by ARS and the Irrigation Industry</u>. Activities in this area have continued to focus on increasing the awareness of Irrigation Industry and ARS scientists and engineers about opportunities for collaborative research. 1) Through a Collaborative Effort initiative, articles on ARS research and other irrigation and water quality information relevant to the Irrigation Industry have become a regular feature in *Irrigation Business & Technology*, a bi-monthly publication of the IA. The fourteen ARS I&D locations are contributors with an introduction for each issue's article by the ARS National Program Leader for Water Management and Water Quality. 2) The directory of "Irrigation & Drainage Research in the Agricultural Research Service" (the "yellow pages")[3] underwent a third update in 1996. 3) For the sixth consecutive year, outreach efforts, including "how-to" information for entering into Cooperative

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[1] Dedrick and Heermann (Water Management Research, Ft. Collins, Colorado) have co-chaired the Collaborative Effort. Key input to the process has been provided by J. A. Chapman, Valmont Industries, Valley, Nebraska; L. E. Stetson, ARS, Lincoln, Nebraska; and S. A. Rish, ARS, Phoenix, Arizona, as Subgroup Co-Chairs; T. A. Howell, ARS, Bushland, Texas, for development of the "yellow pages"; and consultant D. B. Levine (Management/Team-Building Specialist) for overall facilitation of the Collaborative Effort.

[2] The original list was developed in 1992 and presented to ARS in 1993. See p. 5, 1995 USWCL "Annual Research Report," regarding the ARS response.

[3] The "yellow pages" lists current ARS I&D researchers by location, their areas of expertise, and the accomplishments and publications of each of the fourteen I&D locations. For copies, contact The Irrigation Association, 8260 Willow Oaks Corp. Dr., Ste. 120, Fairfax, VA 22031; tel. (703) 573-3551; fax (703) 573-1913.

Research and Development Agreements (CRADAs) with ARS, will be extended through the Collaborative Effort exhibit at the 1996 IA Exposition, to be held in San Antonio in November. Support for the exhibit continues to be provided by IA and the ARS Offices of Technology Transfer, Interactive Cooperation, and Information. The exhibit will be staffed by ARS locations at Phoenix, Ft. Collins, and Bushland and Lubbock, Texas. Martha Steinbock, OTT, Albany, California is coordinating the exhibit.

- Proposing and Supporting the Water Science and Technology Board Irrigation Study. A two-and-a-half-year study of the future of irrigation, proposed to the National Research Council Water Science and Technology Board (WSTB) by the Collaborative Effort, has been completed; and the study report, *A New Era in Irrigation*,[4] will be available in October. Heermann served on the study committee, and Dedrick provided liaison between the Collaborative Effort Leadership Group and the study committee. Funding was provided by The Irrigation Association, USDA-ARS, USDI-Bureau of Reclamation, Ford Foundation, and National Water Research Institute.

INTERPRETATION: The combined efforts of the Irrigation Industry and ARS have produced significant accomplishments, which can be expected to have continuing impact. Hundreds of industry representatives and other users have been reached through the annual IA Expo exhibits, the "yellow pages" directory of ARS Irrigation and Drainage researchers, and other materials. The ARS articles in *Irrigation Business & Technology* reach about 12,000 users. One of the specific goals of the articles is to provide information on cooperative research opportunities. The WSTB study report on the future of irrigation will be available to the public and other interested parties. As with earlier WSTB studies, it can be expected to serve as an unbiased, in-depth examination of the issues and, as such, to be used for policy and political decisions. Industry representatives to the Collaborative Effort have noted how the process has provided a successful experience in building ongoing interaction, understanding, and trust between a client group (in this case the Irrigation Industry and ARS), and show a willingness to continue to participate in the partnership. The approach used with the Irrigation Industry has potential as a model for building partnerships between ARS and other client groups, especially as we in ARS move toward more client involvement in our research program development and assessment (i.e., ARS's response to the Government Performance and Results Act).

FUTURE PLANS: The Collaborative Effort Leadership Group, which last met formally in September 1993, will meet again in November 1996. Three focus areas are anticipated: 1) impacting irrigation policy and support of related programs, building on the WSTB and the Council for Agricultural Science and Technology (CAST)[5] reports and USDA policy changes; 2) strengthening the Irrigation Industry-ARS collaboration, research relevance, and policy advocacy, in particular as it relates to the "new" IA/USDA structural and operational directions; and 3) updating other areas of earlier attention. In the interest of broadening Federal representation to include other relevant agencies, members of NRCS and USBR have been invited to participate. Attendees will also include members of the IA Executive Committee. In addition to ongoing outreach efforts, above, efforts are underway to get the "yellow pages" up on the ARS home page. At their November 1996 meeting, the IA Research Committee will continue to develop the Irrigation Industry's research priorities as part of their continuing committee activities .

COOPERATORS: Cooperators are included in table 1.

[4] *A New Era in Irrigation*, the National Academy Press, tel. (202) 334-3313 or 1-800-624-6242, $32.95 (estimated) plus shipping of $4.00 for the first copy and $.50 for each additional copy.

[5] *Future of Irrigated Agriculture*, 1996, CAST, (515) 292-2125, fax (515) 292-4512, $20 plus shipping.

Table 1. Irrigation Industry-ARS Collaborative Effort Leadership Group members and affiliations

Industry and End User Members	ARS Members
John A. Chapman, Valmont Industries, Valley, NE	Dale A. Bucks, National Program Staff, Beltsville, MD
Richard E. Hunter, Hunter Industries, San Marcos, CA	Allen R. Dedrick, U. S. Water Conservation Lab., Phoenix, AZ
Thomas H. Kimmell, The Irrigation Association, Fairfax, VA	Dale F.Heermann, Water Management Research, Ft. Collins, CO
Thomas E. Levy, Coachella Valley Water Dist., Coachella, CA	Terry A. Howell, Conservation and Production Research Lab., Bushland, TX
Barton R. Nelson, Nelson Irrigation, Walla Walla, WA	Shirley A. Rish, U. S. Water Conservation Lab., Phoenix, AZ
Claude J. Phene, Irrigation Consultant, Fresno, CA	LaVerne E. Stetson, Soil/Water Conservation Research., Lincoln, NE
William R. Pogue, Irrometer Co., Riverside, CA	James R. Welsh, Great Plains Systems Research, Ft. Collins, CO
Rodney Ruskin, GEOFLOW, San Francisco, CA	
Kenneth H. Solomon, Calif. Polytechnic State Univ., San Luis Obispo, CA	

HIGH-FREQUENCY, SMALL-VOLUME SURFACE IRRIGATION

D. J. Hunsaker, Agricultural Engineer; A. J. Clemmens, Supervisory Research Hydraulic Engineer; and W. L. Alexander, Agronomist

PROBLEM: The ability to apply light, frequent deliveries of water uniformly to crops with microirrigation is well recognized. However, very few attempts have been made to develop high-frequency, small volume, irrigation management strategies for surface irrigation systems. This is because 1) most traditional surface irrigation methods are not capable of delivering small uniform quantities of water to the field, 2) changing surface irrigation system designs to accommodate smaller applications may require a large capital investment, 3) increasing irrigation frequencies will likely increase operating expenses, and 4) frequent irrigation scheduling requires a higher degree of management.

However, prior research suggests that increased irrigation frequency has an effect on crop yields that could be economically significant. A number of recent research studies conducted in the desert Southwest have demonstrated higher yields for surface-irrigated cotton when irrigations occurred more frequently. One investigation reported 25% higher yields when irrigations were applied once every five days during the cotton's peak boll development period, rather than once every 10-14 days. Studies on high-frequency level basin irrigation for cotton conducted by the USWCL in 1993 and 1994 demonstrated the feasibility and economic potential of high-frequency level basin design and management, as reported in the 1995 USWCL Annual Research Report. However, in the USWCL studies, the yield increase attributed to high-frequency water applications given only during the peak boll period was on the order of 10%, significantly lower than the 25% increase reported by other investigators. Data obtained during the 1993 and 1994 USWCL studies also suggested that greater yields might be realized if light, frequent, irrigations were continued beyond the peak boll development period. This concept prompted the present field study on high-frequency level basin irrigation for cotton that is being conducted in 1996. The objectives were to determine the effects of small, frequent, water applications given between boll development through boll maturation with level basin irrigation and seasonal daily subsurface drip irrigation on the water use, growth, and yield of cotton.

APPROACH: The 1996 cotton irrigation study is being conducted on a 1.25-ha (108-by-116-m) dead-level field site at The University of Arizona Maricopa Agricultural Center. The soil is a Mohall sandy loam. The site is equipped with a permanent subsurface drip irrigation system with drip tape installed at 1.0-m spacings. A short-staple cotton cultivar (Deltapine-55) was planted in the 1.0-m rows in moistened raised beds on April 17, 1996, at a planting density of 10 plants per meter of row. After planting, the field was subdivided into three blocks each consisting of three, 12-by-115-m basins. Three irrigation treatments were randomly assigned to one of the basins within each block. The three irrigation treatments were 1) low-frequency level basin irrigation (LL), 2) high-frequency level basin irrigation (HL), and 3) daily subsurface drip irrigation (DD). Irrigation scheduling for the two level basin treatments was based on allowable soil water depletion as determined with AZSCHED, a computer-based irrigation scheduling model developed by the Agricultural and Biosystems Engineering Department, The University of Arizona. The model incorporates local meteorological data with a crop coefficient curve for cotton and soil water holding characteristics of the site to calculate the daily water use and soil water depletion of the crop and predict the times and amounts for irrigation. The allowable soil water depletion used for the LL treatment was 55%. The allowable soil water depletion used for the HL treatment was also 55% until early boll development and then was changed to 30% to initiate the frequent, light irrigation regime for that treatment. The period in which frequent, small-volume, irrigation will be applied to the HL treatment began in late June and will continue through boll maturation (late August). The initiation of the daily drip treatment was begun on June 6, 1996. Prior to that date, the DD basins were surface irrigated at the same time and with the same water application depths as the two level basin treatments. Because the soil water depletion of the DD treatment was less than field capacity on June 6, daily water application depths were allowed to exceed daily crop water use for several days in order to raise the level of soil water content of the DD treatment

to near field capacity. Afterwards, the DD irrigation depth was adjusted to match estimated daily crop water use, as calculated by the AZSCHED program.

Data collected during the field study include measurements of water applied during each irrigation, soil water contents, crop evapotranspiration and transpiration, canopy reflectance and temperature, leaf area index, plant biomass, and lint yield.

FINDINGS: Findings through early August 1996, indicate that the HL treatment is exceeding the DD and LL treatment in terms of leaf area and plant biomass. Cotton yields will be determined in October 1996.

INTERPRETATION: The most prominent economic benefit from high-frequency level basin management is potentially higher yields. Previous work demonstrated that smaller, more frequent water applications can be applied uniformly to cotton in farm-scale level basins after normal soil cultivation operations cease at mid-season. Therefore, continued high-frequency irrigation into late season should be possible with level basins. This irrigation scheme is expected to increase cotton yields without increasing the total amount of water applied during the season and without the additional expense of pressurized irrigation system. If successful, high-frequency level basin irrigation management will appeal to cotton growers operating under a small profit margin.

FUTURE PLANS: Future work includes plans to repeat the high-frequency level basin and drip irrigation study in 1997. Additional plans-are presently being developed to evaluate the efficacy of light, frequent, water applications in level furrows with 32" cotton rows with irrigation in every other furrow and with conventional 40" rows with furrow compaction.

COOPERATORS: D.D. Fangmeier, Department of Agricultural and Biosystems Engineering, The University of Arizona.

SURFACE IRRIGATION MODELING

T.S. Strelkoff, Research Hydraulic Engineer; and
A.J. Clemmens, Supervisory Research Hydraulic Engineer

PROBLEM: Throughout the irrigated world, water is applied to fields unevenly and locally in excessive amounts, leading to wastage and to pollution of surface and groundwaters receiving the excess. The interaction of the many variables significantly influencing the movement of irrigation streams down fields, and ultimately, the distribution of infiltrated water and the amount of runoff from the irrigation, is too complicated for simple calculation. A mathematical model--a numerical computer solution of the pertinent governing equations--supplied with the conditions of the irrigation can, on the other hand, allow rapid determination of the consequences of a given physical layout and proposed management procedure. Systematic, repeated simulation allows determination of design parameters to yield optimum uniformity of infiltrated water and minimum runoff from the end of the field. This, in turn, can reduce the degradation of groundwater supplies by excess irrigation water contaminated by fertilizers and pesticides percolating below the root zone of the crop. Similarly, reduction and re-use of field runoff protects surface-water supplies downstream from irrigated fields.

To make a significant impact on surface-irrigation design and practice, computer models of the process must be of broad scope, fast, and reliable, yielding simulations for every reasonable combination of circumstances, and with convenient, user-friendly data input and graphical display of the results of any given set of design and management parameters.

Current models of surface irrigation require further development to extend the range of conditions to be simulated and to increase the reliability of their algorithms. New irrigation techniques generally precede attempts at simulation, so models must be revised to allow theoretical study of the innovations. Furthermore, present models do not always complete a simulation. A variety of physical conditions that can derail a simulation include streams that shrink in length following, say, cutback; very low flows in furrows or borders that exhibit variations in properties with distance; and following surges overtaking earlier releases. The current ARS surface-irrigation model, furthermore, requires data entry more complicated than many potential users are willing to negotiate.

In additionr, most models are limited to one-dimensional flows: single furrows, or border-strips with zero cross-slope and uniformly distributed inflow. But large basins are often irrigated from a corner inlet, or from the middle of a side. The flow spreads out in all possible directions, and any one-dimensional simulation must be viewed as a very coarse approximation. Furthermore, actual departures in the basin surface from a theoretical horizontal plane influence the flow; with the irrigation stream favoring the lower-lying areas, the infiltration uniformity can be significantly affected. Only a two-dimensional model can properly simulate these factors.

The aim of development in both the one-dimensional and two-dimensional contexts is to provide simulation models capable of providing quick results for various test combinations of design and management parameters.

APPROACH: For one-dimensional simulation, user-friendly, menu-driven data input and output (the latter as graphs and text) are linked to a simulation engine based on the universal laws of hydraulics. Constants in commonly accepted empirical equations for infiltration and roughness are entered as input. Program development involves extensive coding in Watcom FORTRAN and C++ (for the ZINC 4.0 menus). Funding for this effort is currently being provided by the Natural Resources Conservation Service.

Two-dimensional simulation is also based on hydraulic principles. With flow velocities small enough to neglect all acceleration, force components in each of two mutually perpendicular directions on the field are in equilibrium. The resulting parabolic partial differential equations in the two directions and time yield a wave-like solution encompassing both wet and dry areas of the field. Calculated depths of flow in the nominally dry areas are many orders of magnitude smaller than those calculated within the irrigation stream, making demarcation of a nominal advancing wetting front easy. Infiltration is assumed to begin only after this wetting front arrives, and to stop after the calculated depth drops below a specified small value.

FINDINGS: Release of a user-friendly, menu-driven, one-dimensional surface-irrigation model, SRFR, version 3.0, is approaching completion and distribution to cooperating researchers. Suggestions from an advisory group of potential users of the software are being implemented in a graphical user interface for input and output. Because the majority of users will not be taking advantage of the program's advanced features (such as spatial and temporal variability of field parameters, or dimensionless input and output), a two-tiered, user-selectable pathway to data entry is made available: standard surface-irrigation operation is enabled through a "standard" subset of data-entry screens; "advanced" usage of the program allows the full range of data entry. The data is shared with a simulation engine linked to the input/output subroutines. On PCs possessing extended memory beyond the 640K DOS range, execution is enabled via Watcom's DOS4GW memory manager.

In the simulation engine, premature calculation of negative depths in the surface stream was found related to large depths of infiltration during the advance of a thin irrigation stream. This arises with large infiltration rates, small stream sizes, long advance times, and especially, restarting advance after a long duration of nearly stationary stream front following front-end recession. It is now thought that the moving grid, found so computationally effective for many cases of surface irrigation flow, is the source of the problem because of the potential for interpolation errors in the infiltration profile as the computational node points are moved about.

A pilot version of a two-dimensional model allowing specification of variable bottom elevations has been constructed on the basis of a linearized implicit numerical scheme. Some results of the model simulating flow over the irregular terrain of a Spanish irrigation basin (with varying inflows and standard deviations of elevations up to 30 mm), have been compared with those from a quite different model (explicit solution of the complete Saint Venant equations for advance, and a horizontal water surface after cutoff, with each local depth infiltrating in place, for recession). Very good agreement has been noted for advance and reasonably good for recession.

With isotropic roughness, the drag force at any location in the field is oriented collinearlly with and opposite in direction to the vector velocity of flow; the hydraulic conveyance in this case is a scalar. For anisotropic roughness, e.g., as the result of some tillage practices that leave small corrugations parallel to one side, the drag and velocity vectors are not collinear; i.e., the gradient of water-surface elevation lies at some angle to the resultant flow velocity. In this case, the conveyance is a tensor quantity.

In an effort to allow an increase in time step over those used in the aforementioned models, a nonlinear, implicit numerical scheme with the resulting simultaneous equations solved as a series of one-dimensional formulations in alternating directions at each time step has also been constructed. Preliminary testing of the model in both one- and two-d contexts has shown its applicability, but it has yet to be engineered for routine practical application.

INTERPRETATION: The response of cooperators to early versions of the SRFR data entry screens has been positive, and a useful, user-friendly version 3.0 is anticipated in the near future. The agreement between the results of greatly different two-dimensional models generates confidence in each one. It is likely that the current study of the interrelationship among distribution uniformity of the infiltrated depths and standard deviation of surface elevations and inflow rate will provide a useful adjunct to current basin-design software.

FUTURE PLANS: Current deficiencies in one-dimensional-model behavior as outlined above will be addressed, exploiting the ZINC-WATCOM development software combination. In particular, the computational grid structure will be reexamined and the stationary grid reevaluated. Release of a beta-test version of SRFR 3.0 to cooperating professionals is contemplated for the start of the calendar year, with a general release a few months later. The pilot two-dimensional model will be reconfigured for routine application; it will be extended to nonrectangular field configurations, and numerical solution parameters will be adjusted automatically in response to solution behavior; a general review of these parameters will be undertaken with the aim of speedy, robust performance. Additional field verification will be sought.

COOPERATORS: NRCS, National Water and Climate Center (Thomas Spofford); CSIC, Spain (Enrique Playan); Instituto de Agricultura Sostenible, Spain (Luciano Mateos); Univ. of Arizona (D.D. Fangmeier); NRCS, Dexter, MO (Keith Admire);Oregon State Univ. (Marshall English); Gila River Farms (Roger Stone)

SOFTWARE FOR THE DESIGN AND MANAGEMENT OF SURFACE IRRIGATION SYSTEMS

T.S. Strelkoff, Research Hydraulic Engineer; and
A.J. Clemmens, Supervisory Research Hydraulic Engineer

PROBLEM: Surface irrigation, in general, is perceived as an inexpensive low-efficiency method of irrigating crops, bound by inherent characteristics and traditional practices to wasting much, if not most, of the water applied. Furthermore, irrigation water that passes through a farm and discharges into the environment is often chemically changed through contact with soil salts, fertilizers, and pesticides. More efficient irrigation would reduce return flows from irrigation to a minimum and so reduce the potential for contamination of surface- and groundwaters.

Suggested alternatives include conversion to high-tech point application--microirrigation--or simply retiring agricultural land out of production. While limitations on application efficiency do exist, depending upon specific field conditions, current procedures for designing field dimensions and operational parameters are inadequate. The complexity of surface-irrigation hydraulics has led to design and management that are largely empirical and greatly dependent on individual judgment and experience.

In recent years, the hydraulic complexity of surface irrigation has been largely overcome through the development of simulation software based on the laws of hydraulics and capable of predicting the performance of an irrigation, given the specific conditions. Infiltration is a major parameter in determining the behavior of a surface-irrigation system; yet its prediction in the field is currently uncertain. Furthermore, each simulation, taking from a few seconds to several minutes to perform on contemporary PCs, yields the results for just one set of conditions. Before such results can be used in design, some procedure is needed to lead the user from a trial set of design parameters to a better one, in the search for an optimum. A program for design should indicate the best possible potential performance, as limited by the field conditions, as well as how to achieve it. It should also indicate how management could respond to seasonal changes in field parameters, once these are evaluated.

Recently, design and management criteria based on a database of existing simulations have been applied to laser-leveled basins. As a result, efficiency of water application can be achieved at a level approaching that of more expensive microirrigation. For sloping fields with tailwater runoff, on the other hand, efficiencies of water use lag behind those in level basins by 20% or more. Conversion to level basins is not always technically feasible, as when field slope is great and agricultural soils shallow. Furthermore, the cost of conversion to level basins or capital-intensive pressurized systems can be substantial. With irrigated farming in many parts of the world under severe economic pressure, attainment of conservation goals without expensive conversions is especially attractive.

The objective of this program is a package of field-evaluation and design software that could be used by designers and technical advisors to irrigators to maximize performance at specific sites.

APPROACH: The performance of an irrigation in a basin or border depends on field characteristics (infiltration, slope, and roughness), target depth of infiltration, physical dimensions, and inflow rate and application time. The purpose of the software is to provide the relationships for a range of conditions.

In one approach, several simulations could be performed with selected sets of input variables to yield reasonable estimates of irrigation stream shape and rate of growth for entry into simplified, very quickly executing, volume-balance models that could show the dependence of performance on the design or management variables. In another approach, a large number of simulations is performed, once and for all, to form a database for the design program. Interpolation in the data base allows solution within a continuous spectrum of independent variables. Indeed, in past work, thousands of dimensionless simulations were performed. In the simpler case of level basins, coordinate transformations led to a store of dimensionless data on uniformity, advance time, etc., as functions of unit inflow rate and basin length. From these data, all pertinent performance parameters are derived for any real basin.

In the sloping border case, dimensionless simulations were performed in hypothetical border strips of such great length that the stream never reaches field end. The dependent variables stored from each run were the length and shape of the distribution profile of infiltrated water; any infiltration calculated beyond actual border-strip length constitutes the runoff for that border strip. Given a real or hypothetical-design border with all the conditions

governing an irrigation known, instead of simulating them, the commensurate dimensionless input variables are determined for entry into the stored data; and performance (distribution uniformity, runoff, application efficiency, etc.) is derived from the resultant profile length and shape. The calculation is fast enough to yield a whole screenfull on the variation of performance, as design input varies over a wide range. Such curves show the performance possibilities for the given field conditions as well as the values of design parameters to achieve a given level.

In both level basins and sloping border strips, dimensionless advance vs. time curves are also stored, to allow advance distance at cutoff *R* to specify the duration of the application. Design based on *R* is pertinent, since that is often how such systems are actually operated.

FINDINGS: Software for designing level basins is now in its second release (version 2.0), with an updated manual. The principle performance indicator is distribution uniformity, *DU*. After specifying the field conditions and target depth, the user, in design mode, specifies three variables out of the four--length, width, inflow rate, and *DU*, and the program supplies the remaining one, as well as application time (or *R*). In evaluation mode, in effect, an essentially instantaneous simulation, the user specifies the field parameters, dimensions, inflow and cutoff time (or *R*); and the program yields *DU* and the minimum or low-quarter depth in the infiltration distribution.

For sloping border strips, software, with help screens and a printed manual, has been completed and some 200 copies distributed. As an example of program use, figure 1 shows contours of potential application efficiency for sloping border strip design under specific field conditions and with a given target depth and total available inflow. The contour plot shows a ridge of relatively high-efficiency designs corresponding, generally, to short, wide borders (low unit flow rates) at one extreme, and long, narrow borders (high unit flow rates) at the other. Figure 2 shows the pattern for a higher-infiltration soil (e.g., sandier), with all other conditions remaining the same. Qualitatively, the same observations as made for the first case apply, but at shorter lengths. Conversely, a heavier soil, with a lower infiltration rate than in figure 1, requires very long border lengths to achieve comparable application efficiencies (note the change in length scale in figure 3a). However, with a decision to irrigate more frequently with, say, a 75 mm target application, as in figure 3b, the higher efficiencies occur at about the same border-strip lengths as in figure 1. Similar contour maps can be displayed for inflow management, with a given design.

A deficiency of the software was noted in the shortness of the dimensionless database, for a region of moderate-to-high slopes and low infiltration rates--the contour maps for these conditions are limited.

INTERPRETATION: There is potential for conserving water and reducing the release of agricultural chemicals into the environment by improved design and management of surface-irrigation systems. Efficiencies can be limited by field conditions, but significant improvement over common current values is feasible. A fast, reliable, user-friendly computer program based on mathematical simulations and showing the response of the irrigation system to variations in trial design conditions should be attractive to potential users, such as mobile evaluation laboratory personnel, NRCS field personnel, extension personnel, consultants, and irrigation district personnel.

FUTURE PLANS: The BASIN program will be provided with a component accounting for the influence of imperfect leveling. A similar design program for low-gradient basins is planned. The BORDER Design Aid database of dimensionless solutions will be extended. A complementary program for furrows is planned, as is a program for guiding and assisting in the evaluation of field conditions.

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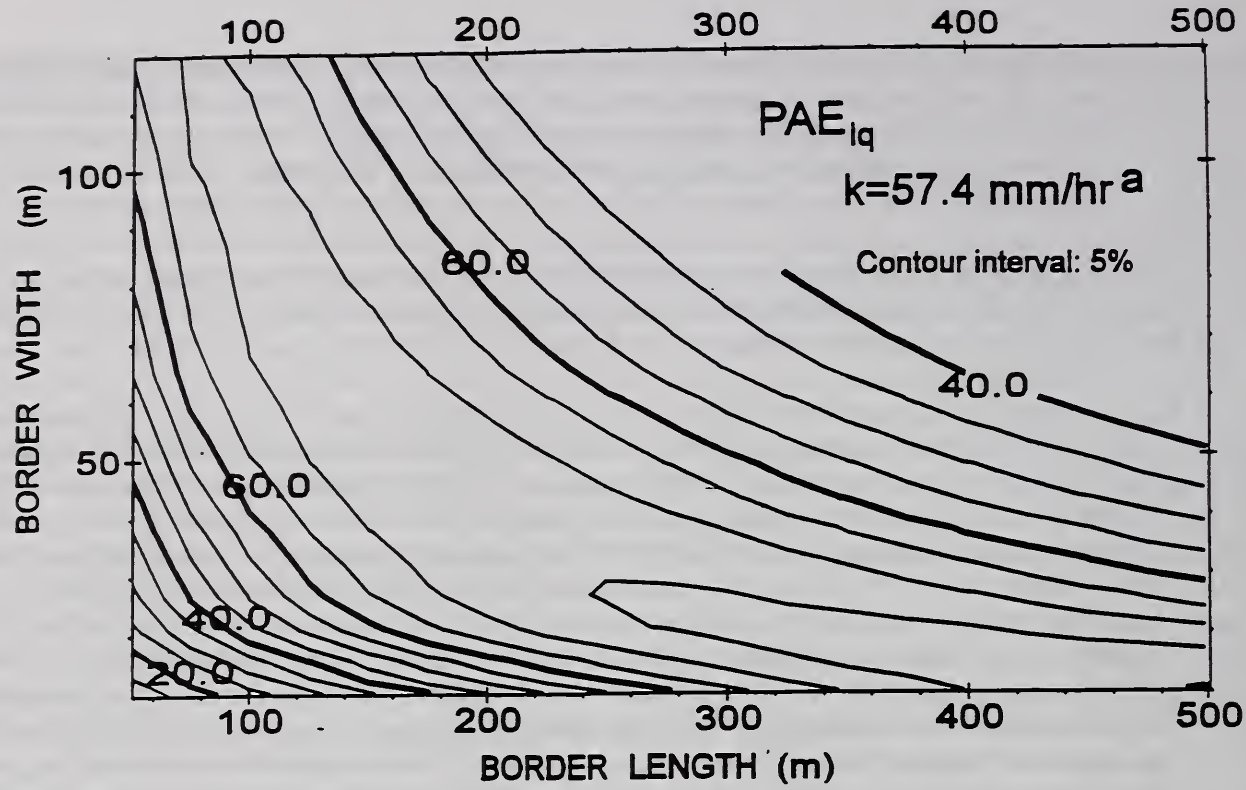


Figure 1. Physical Design: Potential application efficiency. Kostiakov k=57.4 mm/hr^a, a=0.5, Manning n=0.1 m$^{1/6}$, S_0=0.001, Q=60 lps, D_{req}=100 mm

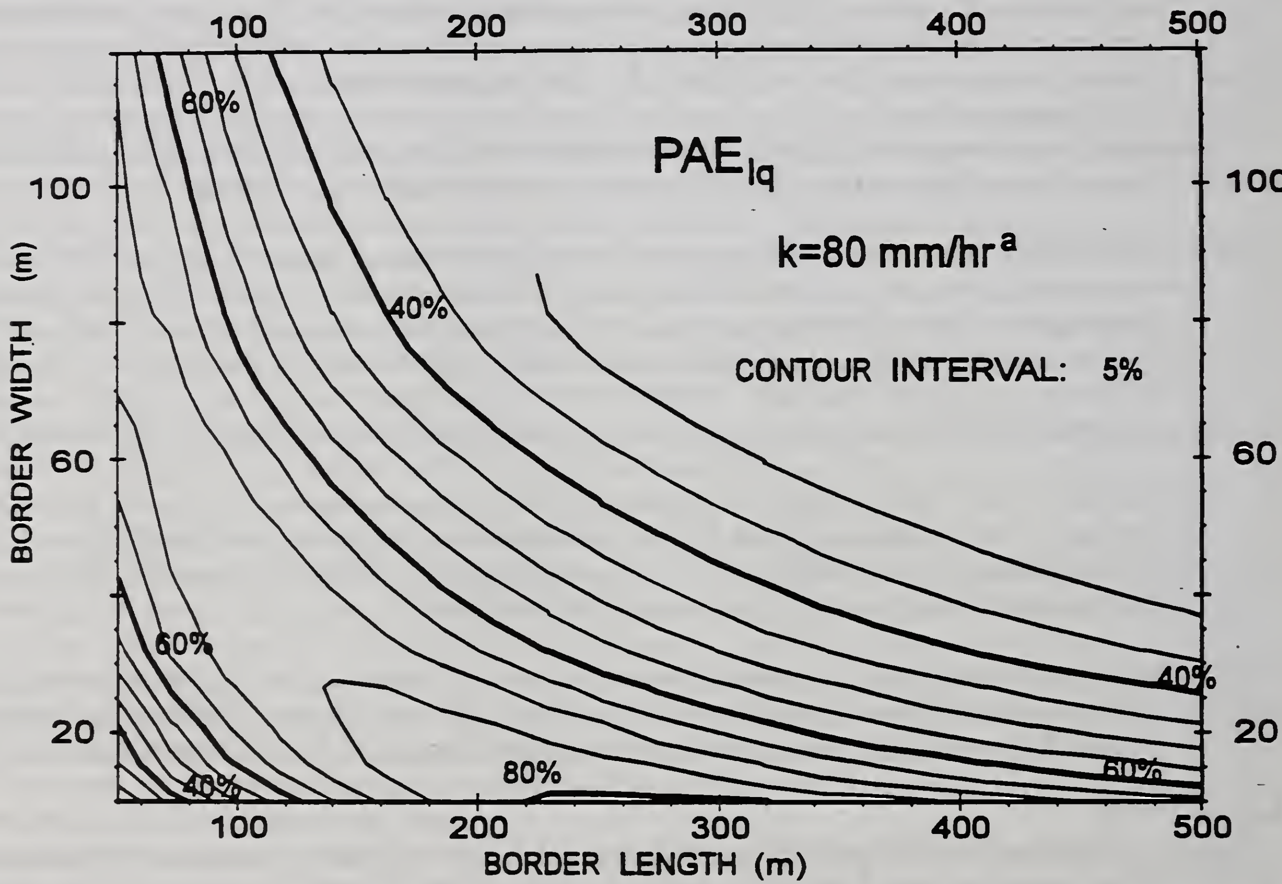
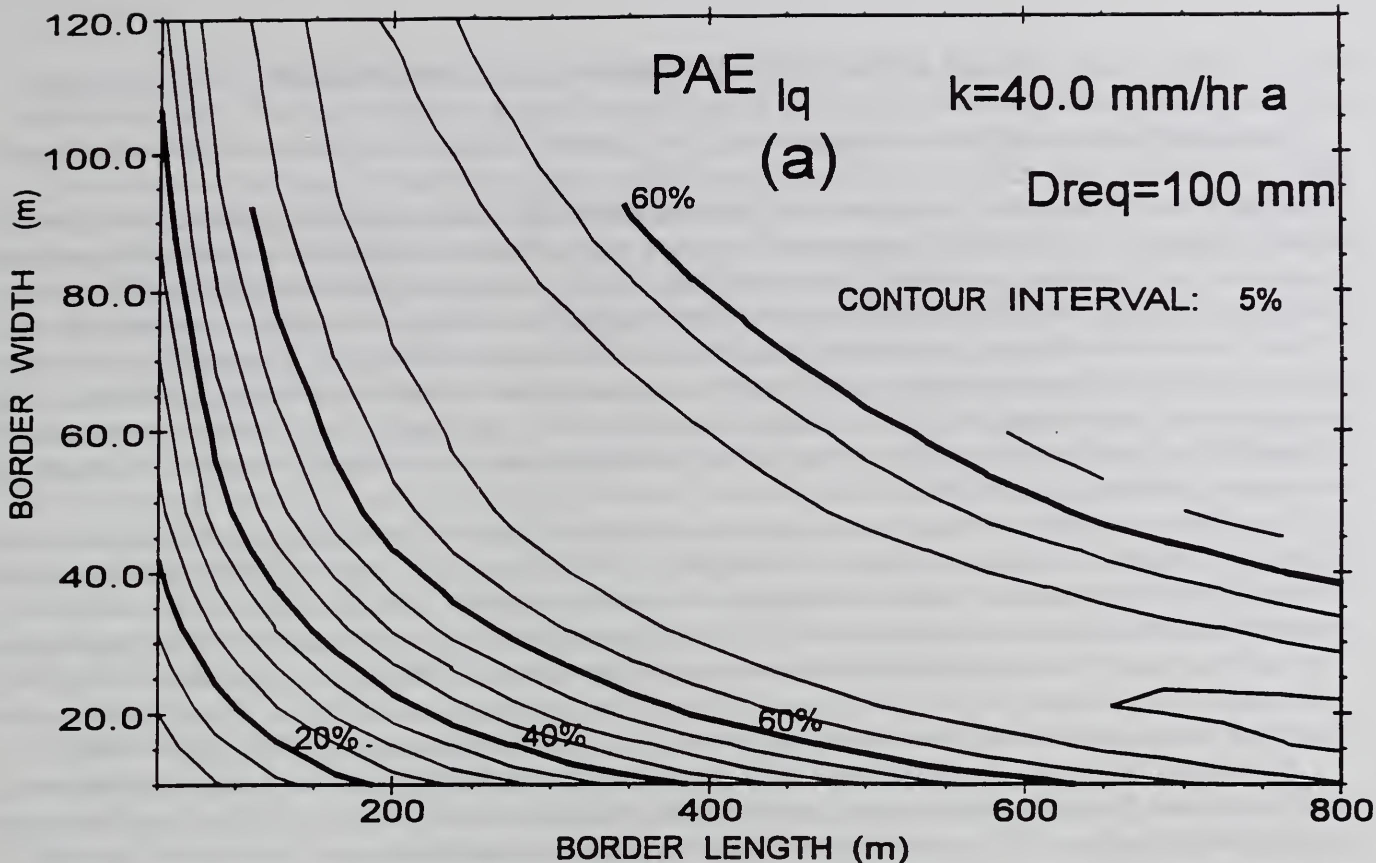


Figure 2. Physical Design: Sandier soil. Kostiakov k=80 mm/hr^a, a=0.5, Manning n=0.1 m$^{1/6}$, S_0=0.001, Q=60 Lps, D_{req}=100 mm



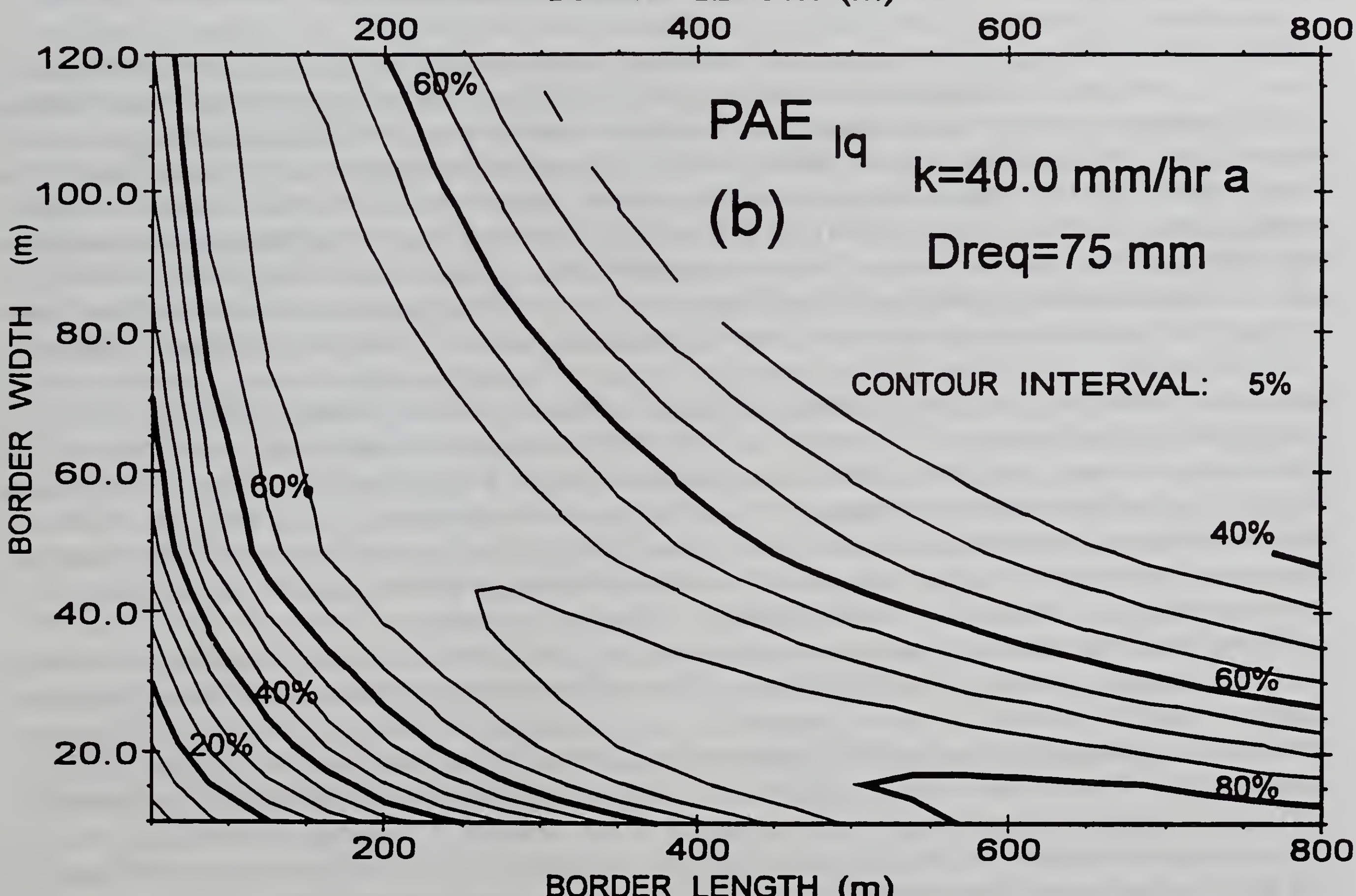


Figure 3. Physical design: Comparison of potential application efficiencies for heavy and light applications. k=40.0 mm.hr^a, a=0.5, n=0.10, S0=0.001, Q=60.0 Lps (a) D req=100 mm; (b) D req=75 mm

CANAL BEHAVIOR AND RESPONSE TO TRANSIENTS

T. S. Strelkoff, Research Hydraulic Engineer; and A. J. Clemmens, Supervisory Research Hydraulic Engineer

PROBLEM: Efficient use of irrigation water often depends on the timely availability of the required flow for the required period. But even with pressurized supply systems, there is no guarantee that with a large number of users, the pressure required to deliver a required rate at a distal point will be available. With the more economical and prevalent canal supply systems, delivery upon demand is considerably more problematic. In a closed conduit, even though pressure drops can limit the outflow at any offtake, any changes in flow anywhere are immediately reflected throughout the system. In an open channel, with the water surface free to rise or fall, changes in discharge propagate as large-scale gravity waves, moving only slightly faster than the water velocities themselves. It could be hours before a demand initiated at a downstream point could be satisfied by increases in discharge at the upstream end, if at all.

These circumstances have led, on the one extreme, to the common practice of scheduling user demands and then setting the pumps and gates in advance. At the other extreme, a variety of supervisory or feed-back control schemes have been proposed to respond to demands initiated at will by a user. Even with advance scheduling, the setting of the gates is often based on the subjective judgment and intuition of personnel with varying degrees of experience, which is often inordinately time-consuming and inaccurate. Measures appropriate to anticipated demands are being studied with inverse schemes of solving the governing flow equations. Strategies for control based on measured canal responses to varying demands, in a feedback loop, are also being considered.

Experience shows, however, that in any case, given control measures have different degrees of success in different canals; depending upon slope, discharge, and other canal-flow parameters. This report deals with quantifying the influence of flow properties on canal response to control measures.

APPROACH: A change in flow rate in a canal is generally accompanied by a change in water-surface profile, even after the transients initially induced by the change have dissipated. The resulting changes in water volume in the canal can be influenced by exercising the gates or other control structures. Whatever the change in volume induced by new flow conditions, a finite time is required for a mismatch in inflow and outflow to produce it. This time is related to the time required to establish the new conditions. Thus, even the study of a succession of steady states is useful in predicting the response time of a canal to changes in regime. Experiential evidence indicates that such predictions constitute an approximation to transient canal response as well. Comparisons of results of the simplified steady-state theory with those based on the Saint Venant equations of unsteady flow should delineate the degree of approximation as a function of canal properties and the timing of imposed transients.

An experimental, generic model of unsteady flow is used in the study instead of existing industrial models because of the flexibility in internal and external conditions afforded by the custom model and to allow input and output in dimensionless terms. This means referencing all discharges to an initial steady-state flow rate, all transverse dimensions (depth, width, elevation, etc.) to normal depth at the reference discharge, all longitudinal lengths to normal depth divided by bottom slope, and all times to a reference time equal to the time to traverse the reference length at normal velocity. In this way, a broad range of canal parameters--base width, side slopes, bottom slope, roughness, length, gate openings, and initial discharge--can be covered without calling for an excessive amount of experimentation and complexity in presenting results.

The method of characteristics was selected as the solution mode for transient flows because of its theoretical correctness and its potential for disclosing facets of flow behavior that could be missed by more approximate schemes. While the model cannot as yet simulate flow after formation of a bore, this condition is not common; and since calculation stops at the computed inception of a bore and an alert printed, there is no danger of spurious computations. The numerical solution scheme serves as a subroutine to a calling program that automatically varies dimensionless input parameters over given ranges. Select measures of canal response are output to a file, one record per simulation. After an appropriate group of simulations has been run (perhaps several hundred), the data from the output file are analyzed and plotted by a separate stand-alone program.

FINDINGS: This project has advanced little since the last report. In earlier work, curves characteristic of possible steady states in a canal pool were constructed on the basis of steady, checked-up water-surface profiles

behind control gates, calculated at various flow rates. These show pool volume as a function of flow rate and checked-up depth. The curves indicate a significantly speedier arrival at a new steady-state discharge with the gates operated to maintain a constant volume in the pool, than when the downstream depth is held constant.

Unsteady pool response to a sudden increase in the flow of a downstream offtake under conditions of ideal control has been studied without any anticipation of flow changes, i.e., under simultaneous, exact replacement of the offtake discharge at the upstream end. In this scenario, with the gate opening fixed, the offtake withdrawal takes place at the expense of pool volume until the replacements initiated simultaneously at the upstream end arrive. The wave motion generated by the offtake results in a drawdown in depth there. The curves, prepared for a range of hydraulic conditions and withdrawal rates, quantify maximum depth reductions.

In a different scenario, in anticipation of downstream withdrawals, some increase in flow is initiated at the upstream end of a pool. In consequence of the canal-pool hydraulics, the step is smeared over time (and with distance, as the wave propagates into the pool) as reflected in the flow hydrographs at various points in the pool. Deformation of the supply wave from a step to a ramp is shown by the time delay between the arrival of the beginning of the wave, defined, say, as 10% of the total step change, and that of the bulk of the wave, say, characterized by the 85% point. The extent of the smearing depends upon distance from the upstream end and somewhat on the Froude number of the flow; it is heavily dependent on the specific downstream-boundary structure. Substantial time delays in the downstream arrival of the bulk of the wave are evident for discharge from the pool through an undershot gate, as compared to a long-crested (duck-bill) weir.

INTERPRETATION: Steady-state analysis yields important results, valid for at least the end points of a transitory phenomenon. Its applicability during the period of the transient remains under investigation.

Unsteady-flow analysis shows that even under conditions of perfect control, replacing offtake demands with upstream flow increases takes time, and that until the replenishments arrive in sufficient quantity, the depth at the offtake continues to fall. The longer the canal, the greater the offtake; and the greater the Froude number of the initial uniform flow, the greater is the maximum drawdown. Calculated curves quantify the behavior and can show when anticipatory regulation is mandatory to prevent excessive drawdown.

Curves documenting the deformation of waves of supply from upstream highlight the overriding influence of the downstream stage-discharge relationship. Further, they quantify the expected effect of pool length and the relatively minor influence of Froude number. The toe of the wave arrives at about the same time with each different downstream structure, while the bulk of the wave (85% of the total upstream step change) arrives significantly later for the gate than for the weir. Much of this delay can be viewed as a response to the higher depths of flow (and hence greater pool volumes) required to pass the increased discharge through the gate opening than over the long-crested weir. This supports the use of such weirs as control structures.

FUTURE PLANS: A publication documenting the selected dimensionless approach to canal studies and the aforementioned applications is in preparation for the ASCE Journal of Irrigation and Drainage Engineering. Canal responses to additional control scenarios will be investigated, including a specified inline outflow hydrograph. The succession-of-steady-states approach will be compared to analyses explicitly treating the unsteadiness. The ranges of parameters in ideal-control and anticipatory-step-increase scenarios will be extended.

For comparison with the method of characteristics, the generic canal model will be extended to include additional control-structure elements and upstream and downstream boundary conditions and multiple pools, as well as an implicit, fixed-grid numerical solution scheme common in industrial models. Simulating additional regimes of flow behavior, such as supercritical flow and bore propagation, will also be investigated.

COOPERATORS: Jean-Luc Deltour, GERSAR-SCP, Societe du Canal du Provence, Aix-en Provence, France; Charles Burt, California Polytechnic State University, San Luis Obispo, CA.

INVERSE COMPUTATIONAL METHODS FOR OPEN-CHANNEL FLOW CONTROL

E. Bautista, Agricultural Engineer; A. J. Clemmens, Supervisory Hydraulic Engineer; and T.S. Strelkoff, Research Hydraulic Engineer

PROBLEM: Development of regulation algorithms for irrigation canals requires a thorough understanding of the relationship between the canal's physical characteristics and its dynamic response. Not until recently has this relationship been systematically investigated. Strelkoff et al. (1995) studied the effect of different types of downstream boundary conditions on the response of single-pool canal systems to upstream flow distrubances. Burt et al. (1995) analyzed the response of canals to idealized feedback control; i.e., by assuming changes in flow downstream were exactly and immediately compensated at upstream control points. Both of these studies considered only the case where control actions were undertaken at the time or after the changes in demand. Since the response of canals to upstream or downstream disturbances is typically slow, steady flow conditions may take still take a long time to be restored even with a sophisticated feedback regulation scheme in place. In real canal systems, changes in demand can sometimes be predicted or scheduled and control actions taken in anticipation of such changes in demand. Therefore, in addition to understanding how a canal responds to a flow disturbance, it is equally important to know what flow changes need to be implemented at control points to achieve a prescribed change in downstream supply. This problem can be studied with a gate-stroking model.

Gate stroking is a computational technique for determining a schedule of canal inflow variations that will deliver a desired downstream discharge variation. The method is based on solution of the partial differential equation system of unsteady open-channel flow. The gate-stroking solutions often require inflow variations that cannot be implemented in practice, such as instaneous changes of large magnitude or flow reversals. Nevertheless, the solutions can be used to analyze the control requirements of canals under different operational scenarios.

In this research, we examine how the properties of the gate-stroking solutions vary under a wide range of canal physical characteristics. The objectives are to better understand the general nature of the gate-stroking solutions, to identify conditions that facilitate or hinder the controllability of canals, and to identify alternative anticipatory control measures that can be used in practical situations in lieu of the computationally complex gate-stroking solutions.

APPROACH: An implicit non-linear finite-difference gate-stroking solution is being used to conduct the study. Tests have shown that the model is nearly as accurate and more robust than an existing method-of-characteristics gate-stroking model. The inflow hydrographs computed with the finite-difference model can exhibit some numerical damping relative to the characteristics solutions under certain flow conditions (i.e., the hydrographs generated by the characteristics model show sharper peaks). However, since sharp flow variations, which are often required by the gate-stroking solutions, cannot be reproduced exactly in the field, the damping introduced by the finite-difference algorithm will likely not compromise the validity of the results.

Multiple simulations with the gate-stroking model are needed to study the properties of the solutions under a wider range of canal characteristics. To reduce the computational effort, the number of considered canal design parameters was reduced by adopting a nondimensional formulation of the governing equations. The dimensionless system of variables used is described in the USWCL 1994 Annual Research Report, pp. 23-26. In that system, depth is expressed relative to normal depth Y_n for the given design inflow Q_n, while velocity is expressed relative to V_n, the normal velocity. With these definitions, the dimensionless depth and velocity at normal flow, Y_n* and V_n*, respectively, are both equal to one. If the canal cross-section is trapezoidal, it follows that the dimensionless normal area $A_n^* = Q_n^* = b^* + ss$, with b* the dimensionless bottom width and ss the side slope (H/V). The dimensioness discharge is then given by Q/Q_R where $Q_R = Q_n/A_n^*$. For canals of uniform slope S_0 and Manning roughness n, their dimensionless equivalents are equal to unity. A family of hydraulically similar canals is then defined by the particular combination of dimensionless variables b*, z, canal length L*, and F_n, the Froude number at normal depth for the design inflow.

FINDINGS: The types of canal relationships that are being studied are illustrated next. Figure 1 shows the specified demand hydrograph for a canal pool with particular nondimensional characteristics. For the example,

we set b*, z, and L* to 2, 1.5, and 0.5, respectively, and allowed F_n to vary. The dimensionless discharge Q* was increased stepwise from its initial value, $Q_n^* = 3.5$, by 10% at dimensionless time T* = 1.0. Backwater conditions were imposed on the example by fixing the dimensionless depth Y* at the downstream boundary at a value of $1.2Y_n^*$. For ease of interpretation, figure 1 and the following figures show the relative discharge, Q/Q_n, rather than Q*. Thus, a relative discharge value of 1 indicates the design inflow while a value 2 is twice the discharge inflow. Tests conducted during 1995 examined exclusively the effect of the flow Froude number at normal depth, F_n, on the gate-stroking solutions. Those tests showed that large temporary inflow increases are needed to produce the desired 10% outflow change at low Froude numbers ($F_n < 0.2$.), but that at higher F_n values (0.4-0.9), the peak transient inflow change is essentially equal to the desired outflow change. Additional tests have been conducted to examine the influence of b*, ss, L*, and the downstream target Y* on the solutions.

Figures 2 and 3 illustrate the effect of the dimensionless bottom width b* on the gate-stroking solutions for F_n values of 0.1 and 0.4, respectively. For the lower F_n value, the peak relative discharge decreases from about 5 to 2.5 as b* decreases from 1 to 5. Thus, for $F_n= 0.1$, the desired outflow changes will be easier to produce if the initial flow is wide and shallow than if it is narrow and deep. The relative discharge hydrographs computed for $F_n = 0.4$ are, on the other hand, very similar to each other. These results show that the geometric characteristics of the flow have little influence on the gate-stroking solution properties for larger Froude numbers.

The effect of the canal's side slope on the gate-stroking solutions is illustrated with figures 2 and 4, the first of which represents a canal with a side slope of 1.5 and the second with side slope of zero ss = 0 (rectangular channel). For the rectangular channel, solutions were obtained for only b* = 3 and 5. The peaks of these solutions are less pronounced than those obtained with the trapezoidal canal (ss= 1.5). For b* = 1, the gate-stroking computations generated a negative depth value causing the program to abort. This implies that a gate-stroking solution may not exist under the proposed conditions. Results computed with increasing values of L*, which are not included here, have identified other conditions under which a gate-stroking solution cannot be obtained.

Figure 5 depicts the effect of the target depth downstream Y_{ds}^*. The peak relative discharge increases in magnitude with decreasing Y_{ds}^*. Since greater values of Y_{ds}^* imply greater backwater effects on the canal, these results show that increasing target depths relative to normal depth and, therefore, increasing canal storage, will simplify the anticipatory control problem, i.e., less extreme changes in inflow will be needed to produce the desired changes in outflow.

INTERPRETATION: The results given above are an example of the types of relationships that can be studied using the gate-stroking model expressed in nondimensional form. The analysis shows that, for the basic conditions described by the example canal, there are canal parameter values beyond which a gate-stroking solution cannot be obtained and, thus, the desired schedule of outflow variation may not be attainable. Similarly, the analysis shows that there are flow conditions for which the anticipatory control problem simplifies to a simple time delay problem; i.e., a given inflow hydrograph will produce a nearly identical outflow hydrograph delayed in time. These conditions would be high Froude numbers, short dimensionless pool lengths, and large dimensionless target depths relative to normal depth. A larger number of dimensionless variable combinations needs to be tested before more generalized results can be developed.

FUTURE PLANS: So far, the research effort has concentrated on analyzing the response of single pool canals. The general properties of the gate-stroking solution for multiple-pool canals will be studied later.

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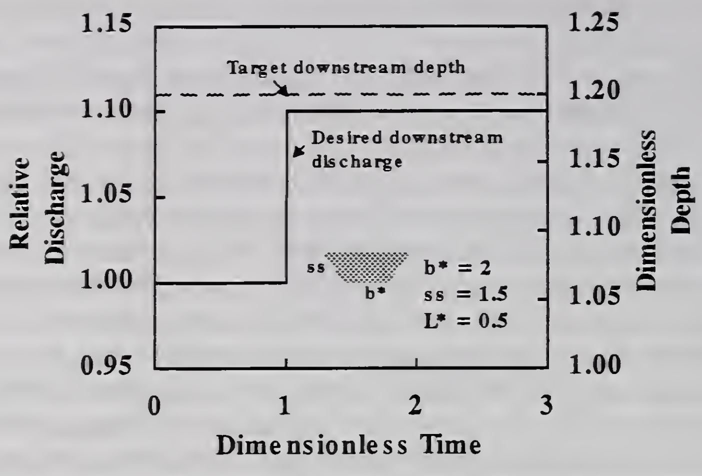


Figure 1. Example dimensionless canal data.

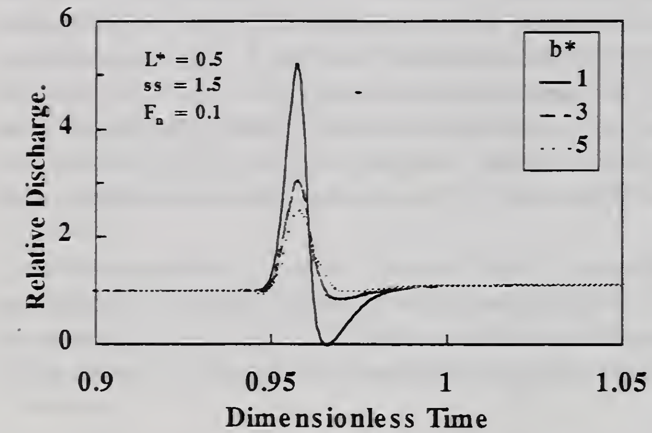


Figure 2. Variation in computed upstream relative discharge with b* for $F_n = 0.1$

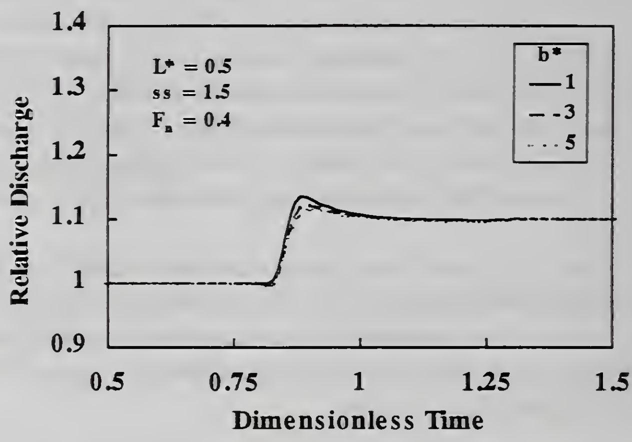


Figure 3. Variation in computed upstream relative discharge with b* with $F_n = 0.4$

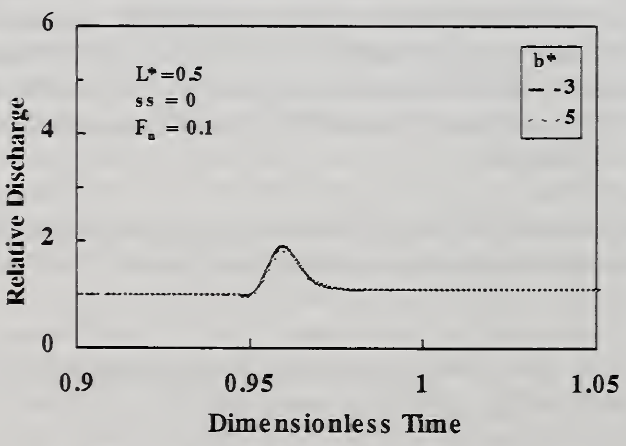


Figure 4. Variation in computed upstream relative discharge with side slope.

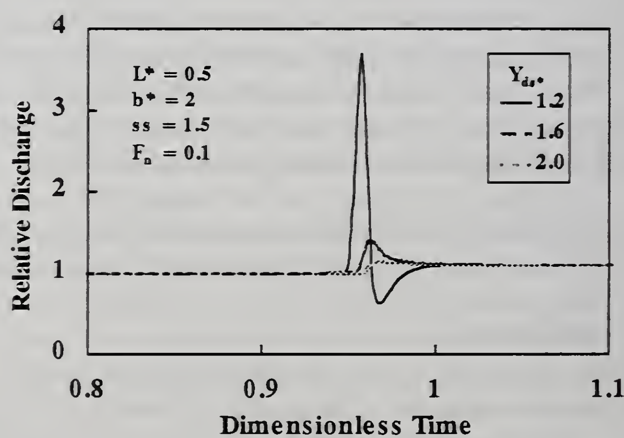


Figure 5. Variation in computed upstream relative discharge with target downstream depth Y_{ds}*.

EFFICACY OF CROP MANAGEMENT STRATEGIES AND SOIL TREATMENT METHODS TO CONTROL KARNAL BUNT OF WHEAT

D. J. Hunsaker, Agricultural Engineer; and F. J. Adamsen, Soil Scientist

PROBLEM: Karnal bunt (KB) of wheat caused by the fungus *Tilletia indica* was detected in scattered areas of the southwestern United States in 1996. Although the impact of KB on the yield and quality of wheat is considered relatively minor when compared to other smuts and diseases of the crop, the presence of KB in the U.S. has significantly disrupted both the local and international wheat trade. Consequently, there is a high level of concern about the potential spread of KB to the principal wheat growing areas of the U.S.. The U.S. Department of Agriculture imposed a five-year quarantine on "hot" KB wheat fields, located principally in desert agricultural areas, in an effort to control the spread of the disease to other locations. However, it is likely that the KB pathogen was introduced to these now quarantined areas at some time in the past, since such diseases do not reach a detectable level until well established. It is also likely that KB spores have already been introduced in areas outside the present quarantine areas. Although the primary means of dissemination of bunt diseases is by infested seed, KB spores can be moved by windblown soil, farm equipment, agricultural products, and by birds and insects that feed on infected grain. Thus, quarantine measures alone cannot stop the entry and establishment of the pathogen to other areas but may delay its entry for a period of time. In addition to exclusionary measures, a range of research efforts is needed to develop effective technologies to lower the level of KB spores in regulated areas and to prevent the spread of KB to other areas. Such efforts include the development of resistant wheat cultivars, equipment and storage facility decontamination methods, seed chemical treatment, soil fumigation methods, and crop cultural practices. The USWCL is cooperating with the Foreign Disease-Weed Science Research Unit on research aimed at developing soil treatment techniques and crop management strategies for KB control.

APPROACH: Studies were initiated in California to determine if soil solarization can be used to treat small fields infested with KB spores in an attempt to return them to wheat production in less than five years. Conjunctive experiments will be conducted on contaminated fields to test the efficacy of soil fumigation with methyl-bromide, methyl-iodine, chloropicrin, and Vapam at varying application rates. Following irrigation of the test plots, small, contained samples of bunted wheat kernels will be buried at varying soil depths prior to the application of each treatment. Monitoring of spore "kill" will be made every 30 days for three months.

Studies on crop management strategies will be developed to determine the effects of soil augmentation, crop species rotation, and cultural practices on KB spore populations. These studies will include the use of lesquerella and crambe crops in rotations, crops that may help reduce KB spore levels in the soil. The overall goal is to develop methods to gradually, if not dramatically, lower the levels of spores in infested fields, as well as prevent the introduction of new inoculum from field infection.

FINDINGS: Permits and agreements were obtained to conduct soil treatment studies on a contaminated field in Blythe, California. The studies were initiated in August 1996.

INTERPRETATION: Successful soil solarization and soil fumigation, if economical, may be used to treat fields in quarantined areas as a safeguard for possible return to wheat production. In Arizona, only a few fields in the Yuma area are presently infected at serious levels. If these fields can be successfully treated with soil solarization, it may be possible to shrink significantly the zone of KB contamination in the Southwest.

FUTURE PLANS: Additional studies on soil treatment methods are planned for next year.

COOPERATORS: Gary L. Peterson, Biologist, USDA, ARS, Foreign Disease-Weed Science Research Unit, Fredrick, MD; Dwight Harder, Laboratory Director, Arizona Department of Agriculture, Phoenix, AZ.

TECHNOLOGY FOR IMPROVED MANAGEMENT OF IRRIGATED AGRICULTURE

IRRIGATION FLOW MEASUREMENT STUDIES IN CLOSED PIPE SYSTEMS

J. A. Replogle, Research Hydraulic Engineer; and B. T. Wahlin, Civil Engineer

PROBLEM: Both propeller meters and end-cap orifices, well established flow measurement devices for closed pipe systems, have a number of significant drawbacks.

Propeller meters tend to become clogged in debris-laden flows. As a result, propeller meters are usually inserted into trashy flows for only a short period of time for just a sample measurement and then removed. Long-term flow integration is not considered practical. Most delivery canal systems use pipes through the canal banks to deliver flows to farm canals. Propeller and ultrasonic meters placed in these pipes frequently are subjected to poorly conditioned flow profiles that severely compromise the meter operations. Methods to condition flows and improve the flow profiles are needed.

Problems with end-cap orifices arise from the pressure taps used to detect the head. A flange tap is located in an area of high velocity gradients and can lead to unstable head readings. Pressure taps located upstream of the orifice introduce a permanent hole in the pipe wall and raise questions as to whether the tap is truly free of burrs. Improving the propeller meter's ability to shed trash and the head detection method for end-cap orifices would make them more useful flow measurement devices.

Flap gates at the ends of pipes exert a back pressure into the upstream piping. Whether this back pressure exists at both low-and high-speed flow is questioned by users as to whether this back pressure is significant to some applications. The effect of gate weight and the stiffness of flexible hinges usually used is not well established.

The objectives are to (a) evaluate prototypes of clog-resistant propeller meters that have been manufactured to our suggestions; (b) develop practical methods to achieve effective flow conditioning in pipe outlets; (c) complete the data evaluation on the end cap orifice; and (d) evaluate the back-pressure effects of flap gates at pipe outlets.

APPROACH: A meter builder (Global Water) in Fair Oaks, California, agreed to construct and furnish two industrial propeller meter prototypes following our design proposals. Plans are to operate these specially constructed propeller meters in clear and trash-filled flows in a 30-inch diameter pipe facility constructed for the purpose in the laboratory. The swept-back (conical) propellers are suspended by their point instead of being held in place from behind (fig. 1). The facility will be used to evaluate the response of the meter to a variety of flow conditions presented to it. A new ultrasonic velocity probe will be used to define this flow field.

Methods to condition the flow profiles in pipe outlets will include insertion of minimum contraction orifices and sidewall vanes.

An alternate pressure tapping system for the end-cap orifice using a small static pressure tube (with holes drilled through its walls) to detect the pressure in the large pipe upstream of the orifice was studied (fig. 2). The tube was inserted through a grommet-sealed hole in the face of the orifice plate near the pipe wall. The pressure sensing holes were placed one pipe diameter upstream from the face of the orifice.

A pipe with a series of pressure tappings will be used to observe the pipe pressures and any changes due to the flap gate installed at the end. Initial studies will use an 8-inch diameter pipe.

FINDINGS: The propeller meters have been installed into the test facility. Data collection is starting, but results are not yet reportable.

The calibration of the end-cap orifice using both flange taps and upstream wall taps was verified using the laboratory weigh-tank system. The static pressure tube was placed in the pipe about 1/4 inch away from the wall. This distance was close enough to the wall so that trash did not become stuck on the tube and far enough away from the wall so that the wall did not affect the head reading. The method of readout based on the static pressure tube was confirmed to be viable. The calibration appears to be stable and consistent with expectations (fig. 3).

INTERPRETATION: These propeller meters use a battery-powered display showing the instantaneous flow rate and total flow for a pipe diameter that can be selected. The meter uses a 10-inch diameter propeller that rotates freely on a stainless steel shaft. The trash resistant propeller meter will eliminate the need for operators

to monitor constantly the propeller meter when it is being used in trashy flows. Instead of using the meter in a debris-laden flow for only short time periods, users can leave the meter in the flow for extended periods of time to record total delivery volumes without clogging.

Implementation of the static pressure tube for field use in an end-cap orifice appears easy to do. This arrangement removes the uncertainty of a flange tap and does not create the inconvenience and uncertainty of drilling into the existing pipe walls.

FUTURE PLANS: Extensive laboratory and field tests will be performed to verify the ruggedness and trash-shedding ability of the propeller meter. To make the laboratory tests as similar to field conditions as possible, the laboratory plumbing has been modified to accept large concrete pipes. The same pipe system will be used for the flow profile conditioning studies.

The Wellton-Mohawk Irrigation and Drainage District near Yuma, Arizona, will provide propeller meter wall brackets and assist in coordinating field testing within the district.

Field-use verification of the end-cap orifice was delayed and must be rescheduled. Field testing and field equipment construction have not been completed but are planned for the fall of 1996. These tests are planned for pumps at the Maricopa Agricultural Center. Further testing is planned in cooperation with the Maricopa-Stanfield Irrigation and Drainage District, Stanfield, Arizona.

Flap gates and the attendant plumbing have been installed. Data collection is scheduled for late 1996.

COOPERATORS: Maricopa Agricultural Center, Univ. of Arizona (Robert Roth), Wellton-Mohawk Irrigation and Drainage District (Charles Slocum), Maricopa-Stanfield Irrigation and Drainage District (Brian Betcher), Global Water (John Dickerman), and Plasti-Fab, Inc. (John Vitas).

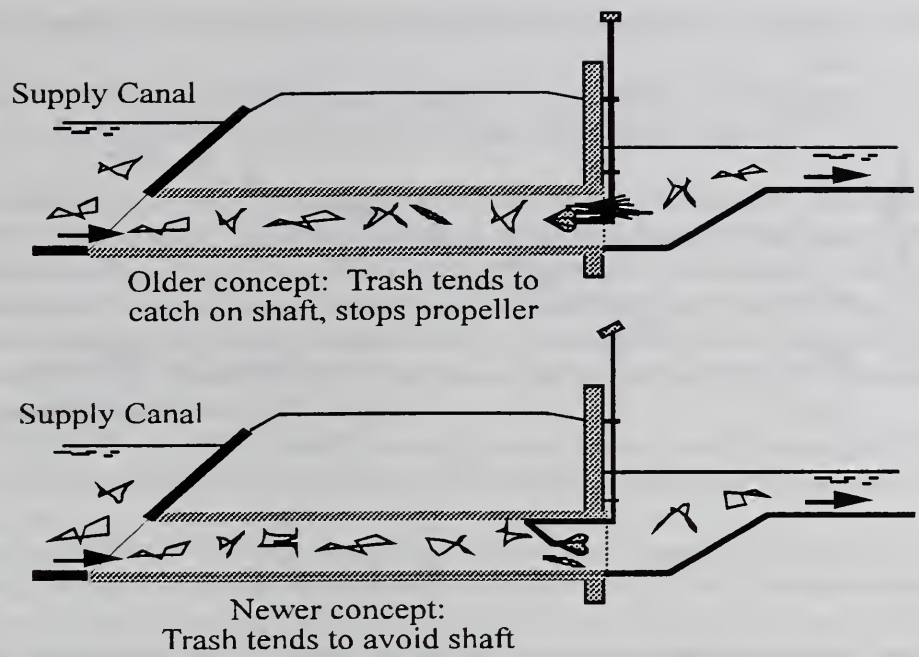


Figure 1. Weed resistant propeller meter.

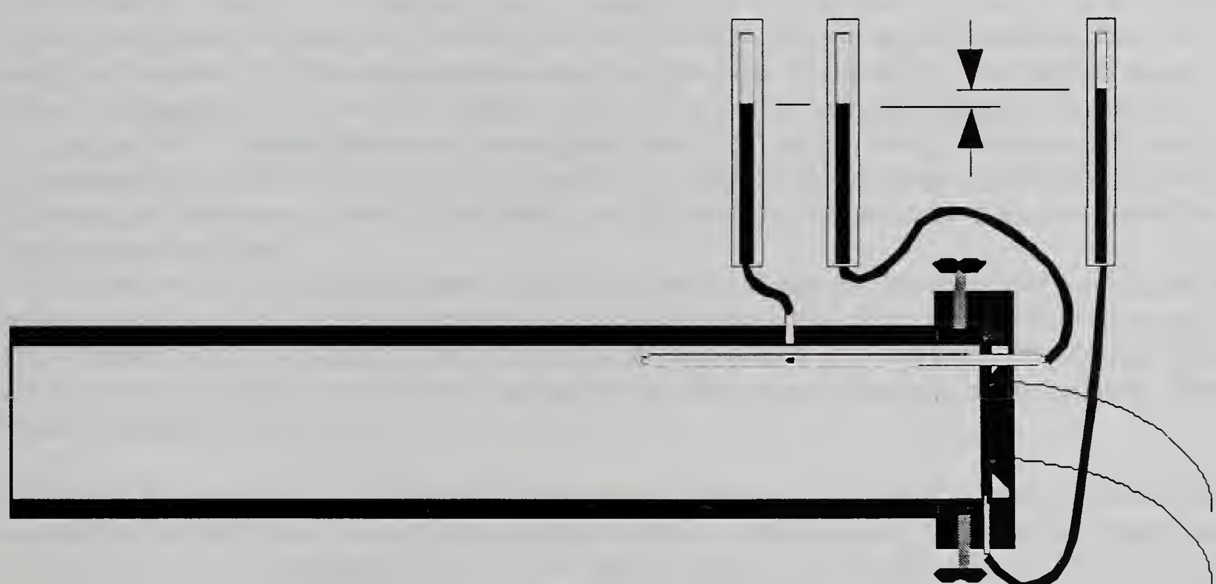


Figure 2. Static pressure probe and wall pressure tap produce similar results, but both differ from flange-tap calibrations.

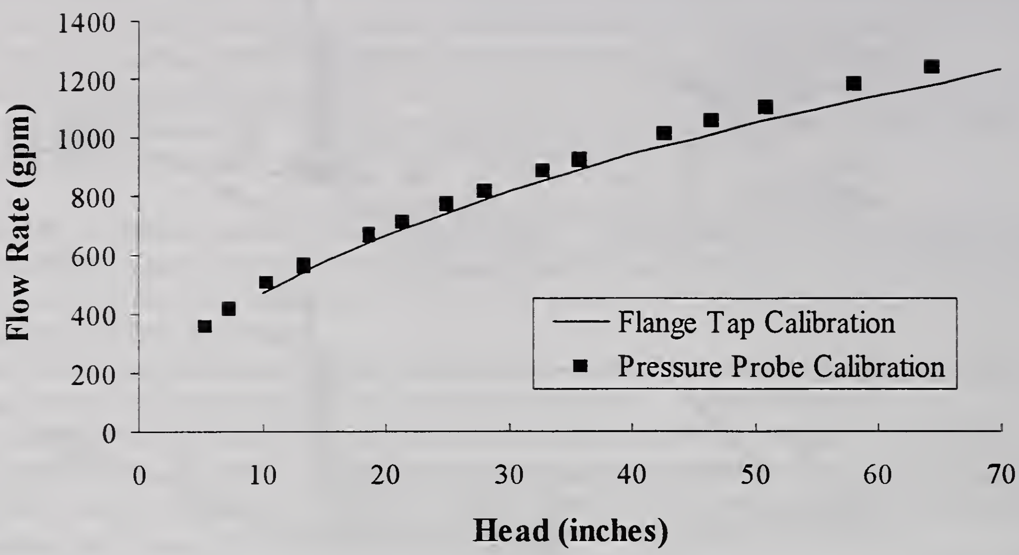


Figure 3. Original calibration based on pressures at the flange-tap location and calibration based on the pressure probe sensing at a distance of one pipe diameter upstream for 6-inch orifice.

IRRIGATION FLOW MEASUREMENT STUDIES IN OPEN CHANNEL SYSTEMS

J. A. Replogle, Research Hydraulic Engineer; B. T. Wahlin, Civil Engineer; and
A. J. Clemmens, Supervisory Research Hydraulic Engineer

PROBLEM: Parshall flumes have been popular flow measurement devices for open channels since their introduction in 1926. Traditionally, problems have arisen in Parshall flumes if they are operated under highly submerged conditions or if they are not constructed exactly to Parshall's specifications. Also, the U.S. Bureau of Reclamation has recently noted a range of submergence in which two values of discharge can occur for the same submergence ratio and upstream head. These problems have compromised the usefulness of many existing Parshall flumes. Further, a large, field-installed Parshall flume appears to have a calibration that differs by 10% to 20% from the historical calibrations for that size.

The objectives are to develop methods to modify wrongly constructed or overly submerged Parshall flumes to recover their function for accurately measuring flow and to identify construction changes that cause significant calibration shifts.

Broad-crested weirs are attractive for open channel flow measurement because of their high accuracy, low cost, ease of construction, and ability to handle high degrees of submergence. One of the most important factors in designing a broad-crested weir is vertical placement of the sill. If the sill is too low, then the flume may exceed its limit of submergence and cease to function properly. If the sill is too high, upstream canal banks may be breached.

The objective is to develop practical, economical versions of vertically adjustable flumes that address the difficulties of precision vertical placement, primarily intended for use in small earthen channels.

APPROACH: The historical calibrations of a standard one-foot Parshall flume and a one-fourth scale model of an eight-foot Parshall flume were verified under both free-flow and submerged conditions using the laboratory weigh-tank system. A false concrete bottom was then placed in the throat of these Parshall flumes to convert them into computable long-throated flumes. The standard stilling well reading point was preserved.

A large (50-ft) Parshall flume was investigated in its field setting using detailed current metering in the downstream channel that included full vertical profiles to verify that the historical 0.6-depth method used to field calibrate the flume was accurate. Additionally, rising bubble techniques were used to examine flow entrance conditions to the flume.

The field problem of deciding on the vertical placement of flumes and broad-crested weirs should be greatly reduced for farm-sized earthen channels by the pending commercialization of a series of three semi-portable, long-throated flumes with adjustable throat sills and capacities of 2, 4 and 6 cfs. Continuing efforts include advice on extended sizes, up to 100 cfs, and calibration information. Handling and installation of the smallest model were field tested.

FINDINGS: Previously, a one-foot fiberglass Parshall flume was installed for study in the laboratory. This unmodified Parshall flume was calibrated under free-flow conditions using the laboratory weigh-tank system. The historically reported calibration for one-foot Parshall flumes was suitably verified. The Parshall flume was also calibrated under submerged conditions, and the anomalous submergence behavior noted by the U.S. Bureau of Reclamation was verified. The Parshall flume modified with the false concrete floor behaved as a long throated flume without having to modify the upstream sensing location.

However, when the studies were extended to a one-fourth scale model of a wide Parshall flume (prototype = 8 ft), which, as expected, suitably calibrated to match the historical prototype, it did not behave as a long-throated flume when modified with a false floor.

New current metering of a 50-ft Parshall flume verified the original field calibrations that differ from published calibrations for this size by 10% to 20%. This flume follows the historical construction except that the rounded entrance was modified to form plane flat surfaces that expand at about one unit in three units distance in the upstream direction. This modified approach section is suspected of causing this difference.

Field testing of the pre-production prototype of the adjustable sill, long-throated flume showed that it could be easily installed in earthen channels, even in flowing water situations. The ability to set the flume on an earthen

bottom with full flow going through a nearly unobstructed flume allowed soil to be shoveled around the outside without eroding away. A reliable seal was quickly made. Then the throat section was raised to achieve appropriate measuring conditions. These flumes are now commercially available in models for 2, 4, and 6 cfs maximum flows under the name "Adjust-a-Flume" (Nu-Way Flume and Equipment Company).

INTERPRETATION: The ability to modify Parshall flumes to behave as computable long-throated flumes opens the way to recover function of wrongly constructed or overly-submerged Parshall flumes. Measuring discharge using a Parshall flume under submerged conditions requires two head readings. Treating the Parshall flume as a long-throated flume removes the need for a second head reading. Also, the modification removes the anomalous submerged behavior noted by the U.S. Bureau of Reclamation on the one-foot Parshall flume. The failure of the wider flumes to respond to the treatment that was successful on the narrower version is thought to be related to the throat-length-to-throat-width ratio, previously not recognized as a potential problem. All previous flume specifications for the long-throated flumes were expressed as functions of depth-to-throat-length criterion.

Vertical placement is one of the most important field decisions for installing long-throated flumes and must be competently supervised to avoid costly refitting or improper function. The development of an adjustable sill long-throated flume nearly eliminates this problem for the farm irrigation user. Also, if the flow conditions change after the flume has been installed, the sill can be quickly raised or lowered to make the flume operate properly instead of having to dig out the flume and reinstall it at a different level. In this movable version, and as a portable device, the ability to collapse the sill allows quick, assured installation using field soil to seal the flume. The main problem with using soil is that it washes away easily, and any disturbance to the initial efforts to seal the flume usually causes undermining and difficulty in resealing.

FUTURE PLANS: A 4:1 scaled-down model of an eight-foot Parshall flume will be calibrated, modified, and evaluated. Because Parshall flumes are not geometrically similar, the model of a large Parshall flume will have a much different proportional shape than a standard one-foot Parshall flume. Length-to-depth relationships in flumes are to be investigated. We plan to evaluate the need to define an additional design parameter in wide flumes with side contractions to replace or supplement the current criterion based only on depth over a raised bottom sill.

The findings for the field installation of the 50-ft Parshall flume will be evaluated on a similar model in the laboratory to determine if the entrance change can cause the recorded deviation from published calibrations for flumes of this size.

Cooperation with U.S. Bureau of Reclamation on evaluating large parshall flumes using both scale models and a new 3-dimensional computer model for hydraulic structures flows that they plan to acquire may be initiated within this next year.

Larger models of adjustable flumes, to be prefabricated and field assembled, are being designed for flows as high as 100 cfs.

An idea for a sediment resistant flume system that combines critical-flow and supercritical-flow flumes for measuring heavily sediment-laden flows has been revived because of the possible interest of a graduate student from the University of Arizona. The concept is based on installing a computable flume at the head of a supercritical flow chute. Recorder equipment is installed on both portions, figure 2. The initial storm flush would provide enough time before sediment filled the flume to give a calibration for the chute portion. Subsequently, the flume is abandoned, and the chute is used to record flow rates.

The new DACL valve reported last year (1995 USWCL Annual Research Report) can be economically mimicked by another valving system that may be more simple. No further work on the valve itself is justified. Efforts will be diverted to laboratory and field evaluations for function and durability of assembled control systems using the concepts.

COOPERATORS: Informal cooperation--USBR, (C. Pugh, Hydraulics Lab., Denver; B. Hamilton, Boise, ID; and R.Dhan Khalsa, Grand Junction CO), NRCS (H. Bloom), Imperial Irrig. Dist. (T. O'Halloran), Salt River Project (J. Kissel, K. Kennedy), Wellton Mohawk Irrig. and Drain. Dist. (C. Slocum), MSIDD (B. Betcher), Plasti-Fab, Inc. (J.Vitas), and Nu-way Flume and Equipment Company (C. Overbay).

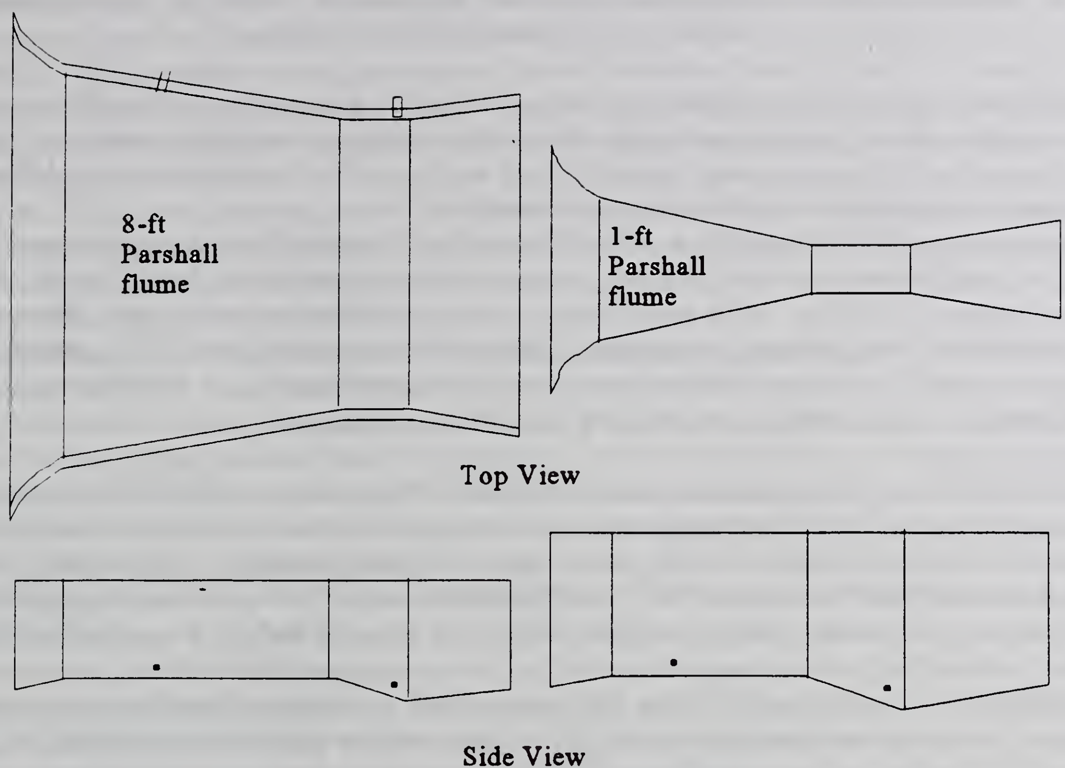


Figure 1. Parshall flumes showing the tested modification and the large proportional differences between a 1-ft model and an 8-ft model (scaled to have the same length).

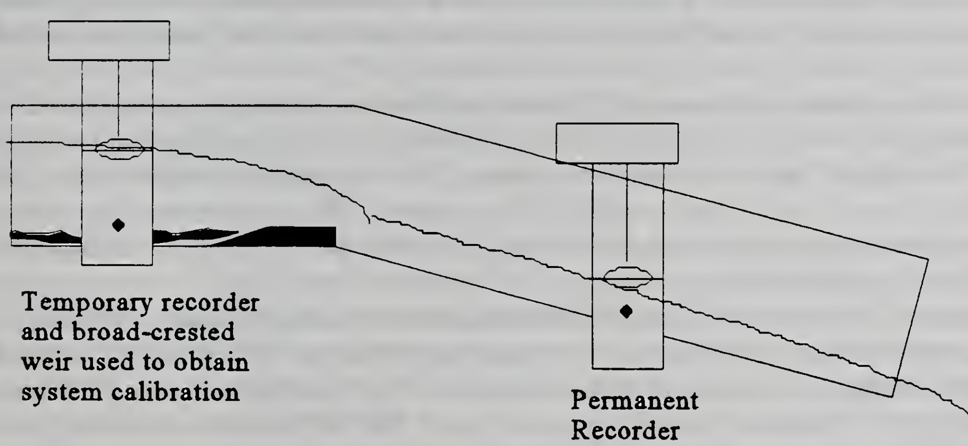


Figure 2. Concept drawing of system to measure flow in streams with large bedload sediments.

WATER-USE ASSESSMENT FOR THE IMPERIAL IRRIGATION DISTRICT

A. J. Clemmens, Supervisory Research Hydraulic Engineer; B. T. Wahlin, Civil Engineer; and J. A. Replogle, Research Hydraulic Engineer

PROBLEM: Changes in cropping patterns, weather, insects, crop markets, etc., can all impact the water use within an irrigation district. Understanding the nature of the changing demands for water, and, further, making judgments regarding its appropriateness, require thorough analysis of the farming systems; including the physical irrigation systems and crop irrigation management practices.

The Imperial Irrigation District (IID) is at the tail end of the Colorado River, where unconsumed water flows to the Salton Sea. IID has been under political pressure to reduce diversions and water flow to the Sea through improved irrigation practices. While some water conservation efforts have taken place, the volume of water flowing to the Sea is still significant (on the order of one million acre feet per year). The purpose of this project is to assist the district in defining current water use with existing information, in develping plans for additional data collections, and in identifying opportunities for water conservation.

APPROACH: A Water Study Team was formed to evaluate the water balance within IID in response to a recent U.S. Bureau of Reclamation (USBR) report that was critical of their water diversions. The team is comprised of Charles Burt and Ken Solomon, Cal Poly; Rick Allen, Utah State University; Ed Craddock, California Dept. of Water Resources; Bert Clemmens, USWCL; and Tim O'Halloran, IID. A water-budget approach will be used to determine the gross annual consumption of water from the Imperial Valley. A weather-based approach will be used to partition this total consumptive use into its various components.

The USWCL is primarily responsible for determining water consumption from the water-budget approach. This method relies on accurate measurement of inflow to and outflow from the Imperial Valley. This approach should work well for this valley since inflows and outflow are predominately on the surface and measurable (i.e., there is very little subsurface flow because of the deep, heavy clay soils).

Five different flow measurement sites were examined in detail during this project: the All American Canal at Pilot Knob, the Alamo and New Rivers at their outlets to the Salton Sea, the New River at the Mexican border, and the flow into the Coachella Canal. The flows in the All American Canal at Pilot Knob and at the New River at the Mexican border are both inflows into IID. The other three sites are considered outflows. All of the sites use current metering to measure the flow except for the entrance to the Coachella Canal, which uses a 50-foot Parshall flume.

To estimate the bias and accuracy at each of these sites, IID's method of current metering was examined to see if they followed the guidelines set by the U.S. Geological Service (USGS). Full profiles (10 points) were taken for a few vertical lines at the outlets of the Alamo and New Rivers. This was done to verify that the 0.2/0.8 method of estimating the average velocity in a vertical is viable for these rivers. Old current-meter data were also examined for the four current-metering sites and the district's calibration of the 50-foot Parshall flume at the entrance to the Coachella Canal was evaluated.

Other surface and subsurface inflows to and outflows from the district were estimated based on data from IID staff, from published geologic and hydrologic reports, and from weather station data. This information was then used to determine total water consumption (primarily evapotranspiration, ET) within the valley, as the remainder in the water budget. Estimates of irrigation water consumption other than for crop production (e.g., canal evaporation, phreatophyte ET, etc.) were then subtracted from the total to determine consumption of irrigation water for crop production. Three other water budgets were used to provide a better picture of the various water uses: inflow and outflow from the district's canal system, inflow and outflow from all farm irrigation systems, and inflow and outflow from the open-drain river system.

FINDINGS: In May 1996, IID began to more closely follow the USGS guidelines for current metering by making sure that each vertical profile contained no more than 6% of the total area. (Errors introduced in prior years by using a constant spacing were less than 1%.) They maintain their equipment well, and current meter the rivers on a weekly basis. The 0.2/0.8 method for determining the average velocity was verified as a good estimate for the Alamo River at the outlet because of its regular cross section (fig. 1). This method did not provide as good

an estimate of the average velocity for the New River at the outlet because of its peculiar cross section (fig. 2). However, because of the large number of vertical velocity profiles used (and thus large number of velocity measurements), the effect of random errors on the flow-rate measurement becomes insignificant. On days that the rivers are not current metered, IID uses a stage-discharge relationship that is adjusted based on the latest current metering. IID's current-metering practices on the All American Canal at Pilot Knob also follow USGS guidelines (see figure 3 for typical cross section). The flow rate in this canal is estimated using a radial gate equation on days that the canal is not current metered. This gate equation is adjusted based on the last four current meterings of the canal.

IID relies on USGS current meterings for the New River inflow at the Mexican border that are performed once a month. IID uses a stage-discharge relationship to estimate flow on days that the USGS does not current meter. A limited amount of data are available for the current meterings on the New River at the Mexican border, and the velocity profiles there are very distorted.

The IID calibration of the Parshall flume at the Coachella Canal heading predicts flows that are 10-20% lower than the standard published values for 50-foot Parshall flumes. The Coachella Parshall flume was constructed properly, and it was never submerged during its calibration. A bubble curtain was placed upstream of the flume to verify that the flow entering the flume had a uniform profile. The Parshall flume was originally calibrated from current meterings taken from January to June 1982. We also current metered it in August 1996 to verify that the 0.6 method is an accurate estimate of the average velocity and to confirm the 1982 calibration (fig. 4). In this case, the current-meter-based calibration appears to be correct. No flaws could be found in the current-metering calibration. The published râting tables for this flume clearly do not match the field calibration. Two possible reasons for this difference are errors in the textbook published calibration or the nonstandard transition between the main channel and the Parshall flume.

Preliminary analysis of the water balance for the year 1987 indicated that total annual water consumption within the valley could be estimated to within less than ±5% (95% confidence interval).

INTERPRETATION: The analysis of water measurement methods for the major inflows and outflows from the Imperial Valley indicates that IID is doing a very good job of measuring water. No strong bias could be detected on the Alamo River at the outlet; however, it was felt that the New River at the outlet had a small bias prior to May 1996 because of the distorted cross-section of the New River and because IID was not following USGS guidelines. No significant bias could be detected for the All American Canal at Pilot Knob. Because of the limited amount of data and distorted velocity profiles, it is felt that there is about a 3% bias for New River flows at the Mexican border. The Parshall flume field calibration accurately predicts the flow in the Coachella Canal with no strong bias. The nonstandard transition between the main channel and flume can probably account for this flume differing from standard tables by 10-20%. The water budget approach appears to provide sufficiently accurate estimates of total annual water consumption in the Imperial Valley.

FUTURE PLANS: No further field work appears to be justified to estimate the bias and accuracy of these flow measurement sites. Additional work needs to be done to determine whether a nonstandard transition between a Parshall flume and the main channel caused a shift in the calibration. Further analysis of the statistics of these measurement sites will be used to more precisely establish their measurement accuracy. These will then be applied to determine the accuracy of other estimates within the water budget. The water-budget approach will be applied to the years 1987-1996.

COOPERATORS: Charles Burt and Ken Solomon, Calif. Polytechnic State University, San Luis Obispo, CA; Rick Allen, Utah State University, Logan, UT; Ed Craddock, CA Department of Water Resources; Tim O'Halloran, Jim Flowers, and Elston Grubauch, Imperial Irrigation District, Imperial, CA; Jeff Agajanian, USGS, Santee, CA; and Robert Meyer, USGS, Sacramento, CA.

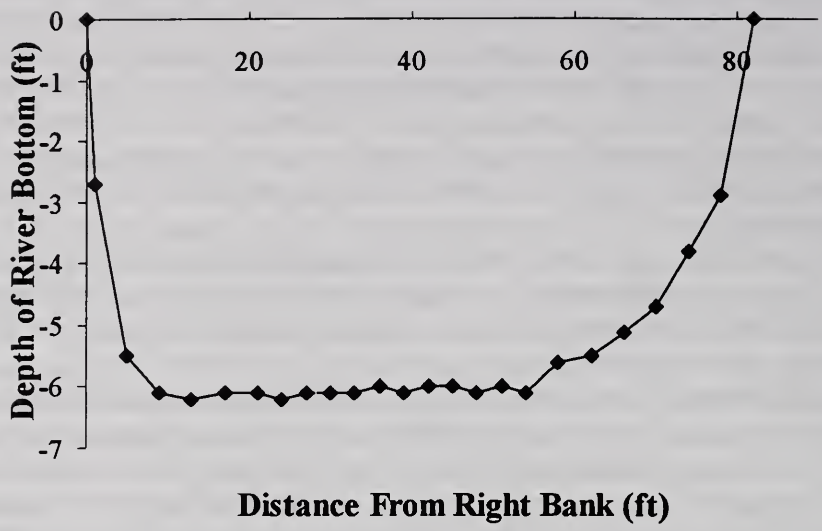


Figure 1. Typical cross section of the Alamo River at the Outlet to the Salton Sea

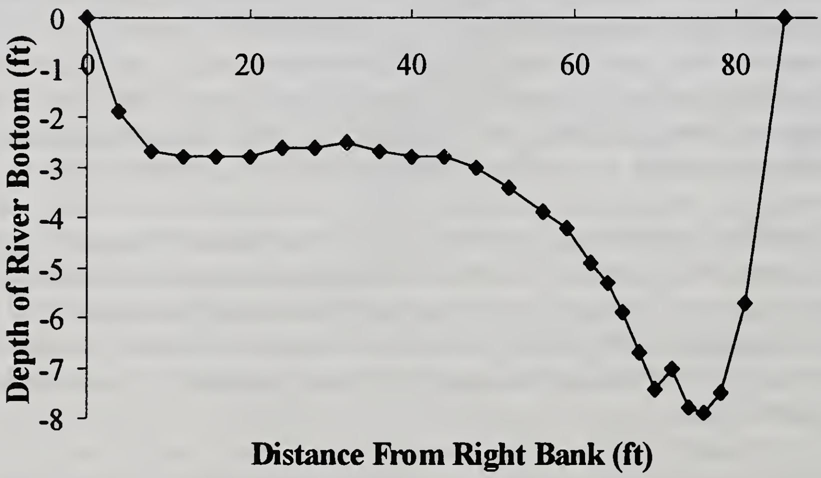


Figure 2. Typical cross section of the New River at the Outlet to the Salton Sea

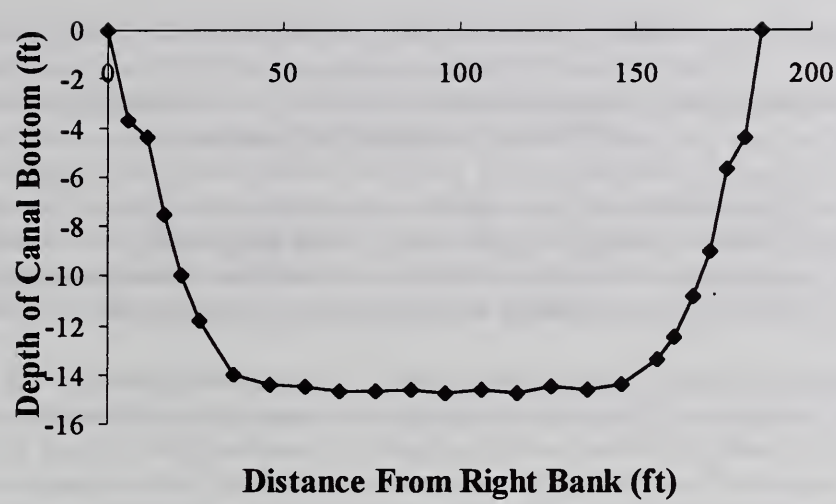


Figure 3. Typical cross section of the All American Canal at Pilot Knob

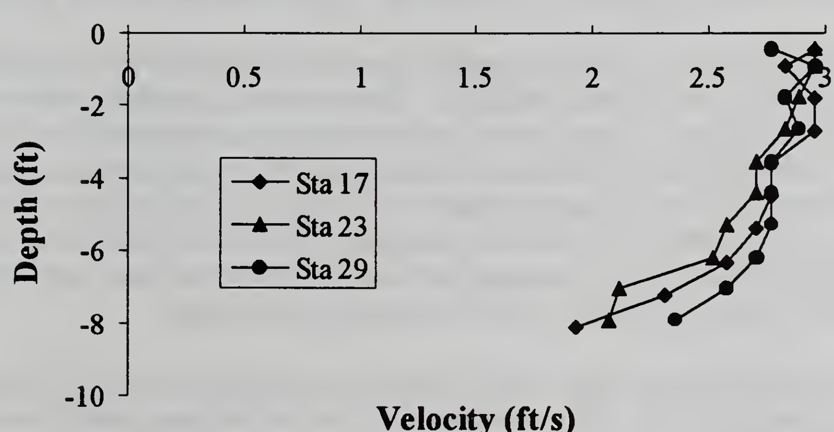


Figure 4. Typical velocity profiles in the Coachella Canal

IRRIGATION CANAL AUTOMATION

A. J. Clemmens, Supervisory Research Hydraulic Engineer; R. J. Strand, Engineering Technician; and E. Bautista, Agricultural Engineer

PROBLEM: Modern, high-efficiency irrigation systems require a water supply with a high level of flexibility and stability. Open-channel water delivery distribution networks are typically not capable of this high level of service. Stable flows can be achieved when little flexibility is allowed since canal operators can force canal flows to be relatively steady. Allowing more flexibility increases the amount of unsteady flow and leads to more flow fluctuations.

Most canal systems operate with manual upstream control. A constant water level at each offtake is maintained to keep delivery flow rates constant. The disadvantage of this system is that all flow errors end up at the tail end of the system. In large canals, supervisory control systems are used to adjust volumes in intermediate pools to keep differences between inflow and outflow more evenly distributed in the system or simply stored until a balance is achieved. Smaller canals with insufficient storage need more precise downstream control methods than are currently available. Development of improved canal control methods requires convenient simulation of unsteady flow by computer. Many computer models of unsteady canal flow have been built in the last 20 years, some very complex and expensive designed to model very complicated systems. Only recently have these programs been geared toward canal automation so that simulation of control algorithms could be made efficiently.

The objective of this research is to develop tools to promote the adoption of improved canal operating methods. This includes development and testing of canal control algorithms, development of necessary sensors and hardware, development of centralized and local control protocol, refinement of simulation models needed for testing these methods, and field testing of algorithms, hardware, and control protocol.

APPROACH: A Cooperative Research and Development Agreement between ARS and AUTOMATA, Inc., was established for the purpose of developing off-the-shelf hardware and software for canal automation. We will work closely with AUTOMATA in the application and testing of these new products. Cooperation with the Bureau of Reclamation's Water Resources Laboratory was also established to support this research.

Theoretical analysis and computer simulation modeling will be conducted to determine the performance and functionality of various control algorithms and schemes. These methods will be field-tested to the extent possible.

Control engineering will be used to develop control algorithms for one or more canals within the Maricopa-Stanfield Irrigation and Drainage District (MSIDD). These control algorithms will be written into control software for the central computer. Where possible, as much logic as practical will be written into the Remote Terminal Unit (RTU) software so that control can be more precise. New gate position sensors will be developed and tested to provide finer resolution of gate movement, while still providing absolute position. Several control algorithms will be tested to compare the various advantages and disadvantages of these controllers and tuning methods. Gate-stroking will be used to determine the kind of feedforward logic needed to route known flow changes through the canal, represented as a series of canal pools with gates.

FINDINGS: A new gate position sensor was designed in cooperation with AUTOMATA. They built a prototype, which we tested in the lab. The new commercial version has been installed on the WM canal gates. Field testing has not been done.

Programming of AUTOMATA's new generation RTU for specific canal automation functions has been started. The development system for these RTUs uses the computer language FORTH.

Automata RTUs were purchased by the Bureau of Reclamation's Water Resources Lab with funding from the Lower Colorado Region's Water Conservation Office. One has been installed in the field for testing purposes. The remaining RTU will be installed in late 1996 or early 1997.

MSIDD has allowed us to use their backup base station to conduct our automation research. AUTOMATA obtained a radio frequency with a four-state license for more straightforward application of their automation systems. Radios with these frequencies were purchased by AUTOMATA for use on this project.

Research on generic approaches to implementing modern canal controllers is progressing. A manuscript on this general approach has been drafted in cooperation with IMTA and TU Delft.

Programming has been done on the implicit finite-difference gate-stroking solution so that it can handle multiple canal pools. An example is shown in figures 1-3. The WM canal was used, with slight modifications in properties, to develop a standard test case by the ASCE Task Committee on Canal Automation Algorithms. For the second test on this canal, several offtake flows are changed after 2 hours (fig. 1). The finite-difference gate-stroking scheme was used to compute the necessary changes in gate flow rates, as shown in figure 2. The accuracy of the computed schedules was tested by using them as input to a simulation model. Figure 3 depicts the resulting turnout flows, which are nearly identical to the desired flows illustrated in figure 1.

INTERPRETATION: This research continues to show promise, but progress was slowed by lack of funding for equipment. This problem has been solved, and the research should move forward more quickly in the coming year.

FUTURE PLANS: The MSIDD WM canal is being outfitted with new RTUs that are more easily programmed with the necessary automatic control functions. Once these are in place, the automation logic will be programmed into the RTUs and central computer software. Field testing of the new routines and sensors will be made off-line. Then, new controllers for the canal will be designed and field tested, including both feedback and feedforward (gate-stroking) components.

A lateral canal with properties somewhat different from the WM canal will be selected for future analysis and testing of control algorithms.

COOPERATORS: Lenny Feuer, AUTOMATA, Inc.; Gary Sloan, MSIDD; Ken Taylor, Central Arizona Irrigation and Drainage District; Jan Schuurmans, Delft U. of Technology, The Netherlands; Charles Burt, California Polytechnic State University; Bob Gooch, Salt River Project; Victor Ruiz, IMTA, Cuernavaca, Mexico; Pierre-Olivier Malaterre, CEMAGREF, Montpellier, France.

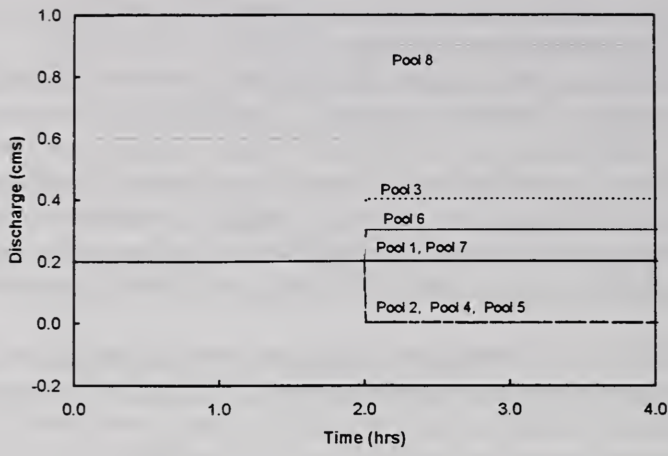


Figure 1. Desired variation in turnout discharge for each pool.

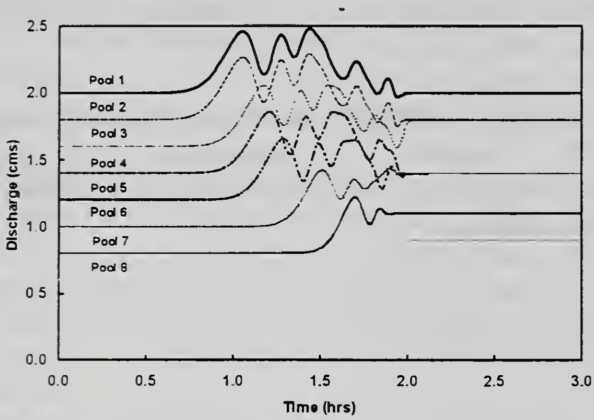


Figure 2. Required variation in check discharge for each pool.

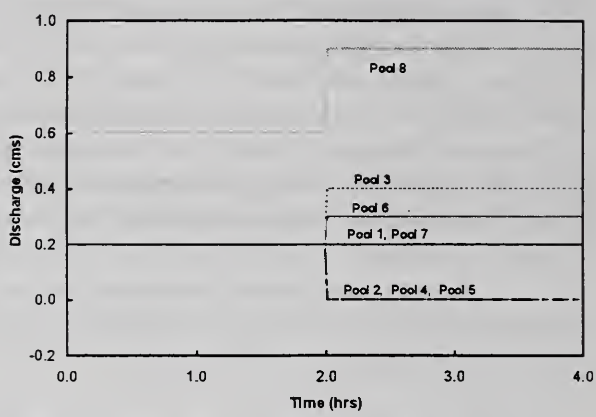


Figure 3. Resulting variation in turnout discharge for each pool.

CANAL AUTOMATION PILOT PROJECT FOR SALT RIVER PROJECT'S ARIZONA CANAL

A. J. Clemmens, Supervisory Research Hydraulic Engineer; E. Bautista, Agricultural Engineer; and R. J. Strand, Engineering Technician

PROBLEM: The Salt River Project (SRP) has a long history of being progressive in the management of its water distribution system. SRP's Roosevelt dam was the first to be built under the Reclamation Act of 1902. The district also assumed control of the distribution network from the Bureau of Reclamation in 1917 to improve service to their water users. SRP developed its own supervisory control system in the mid-1960s, covering its entire network of main canals. In the 1980s, SRP embarked on an intensive water measurement program to reduce unaccounted-for water losses. With the conversion from agriculture to large urban water user, water transfers are becoming a more important issue, and supervisory control operators are spending increasingly more of their time on such issues as water transfer agreements. In the early 1990s, SRP constructed a new operations center with a state-of-the-art SCADA (Supervisory Control And Data Acquisition) system.

Studies in the 1970s by Zimbelman suggested that SRP's main canals could be operated with automatic downstream feedback control. Significant advances have been made in methods for canal automation with feedback control. The objective of this project is to determine the feasibility of implementing canal automation within SRP's distribution network.

APPROACH: A pilot project was initiated with SRP to test the potential of an automatic controller on the first four pools of the Arizona canal. The initial controller will use simple time delays for the open-loop routing of known flow changes (feedforward) and a closed-loop (feedback) controller to handle disturbances or errors in flow settings. In the initial stage of this project, we will study the feasibility of this control scheme through unsteady-flow simulation. If this proves successful, we will explore the possibility of testing the scheme in real time on the canal.

Unsteady flow will be simulated with an existing software package that SRP purchased, MIKE-11. The model was calibrated by the Danish Hydraulics Institute (DHI). SRP will assist us in collecting data on the response of the canal. This data will be used to test the MIKE-11 model calibration under unsteady flow conditions that are typical of control situations. DHI will add a user interface to the MIKE-11 software to accommodate our control logic. Unsteady-flow simulations with MIKE-11 will be made to determine the response characteristics of the pools between check gates. Based on these results, the closed-loop controller will be determined from analysis with the control system software, MATLAB. Next we will program the control logic into the user interface to MIKE-11 so that it can be tested with Mike-11. SRP will develop a series of control scenarios that represent typical operating conditions faced by the supervisory control operators. These control situations will be used to test the various features of the control system through unsteady-flow simulation with MIKE-11.

FINDINGS: The overall properties of the first four pools on the Arizona Canal are shown in table 1. There is some question whether Granite-Reef diversion has sufficient storage to allow pure downstream control on the Arizona Canal. For the current testing, it is assumed that it has sufficient capacity. The results will determine the degree to which this reservoir capacity will limit the application of canal automation.

Flow changes on the Arizona Canal were monitored on three dates to provide a step change in inflow from which we could judge the ability of the unsteady-flow model to track transients. Data from the first date were unusable because of the lack of steady conditions at the start of the test. The results from April 7, 1996, demonstrated that MIKE-11 did a reasonable job of representing the phenomenon (fig. 1). Errors in SRP's gate settings and calibration likely resulted in some of the mismatches in flow between the model and observed data. Results from the April 21, 1996, flow test showed similar agreement.

DHI's MIKE-11 program offers some advantages in modeling SRP's distribution network but has some limitation in incorporating the needed control logic. DHI does not provide access to the source code but has provided some indirect programming capabilities through a user interface. This user interface was not structured in a way to make application of our control system convenient. After several iterations, DHI developed a user

interface that would work, but not without considerable programming effort (and not in a generic way for any canal).

We used the MIKE-11 user interface to implement ideal flow control gates. This was used to determine the characteristics of each pool by making a flow change upstream and observing the change in pool level over time. The first two pools behaved like simple sloping canal pools, with a time delay followed by a gradual rise in water level (fig. 2). The slope of this rise in water level for a given flow change approximately represents the water surface area of the backwater behind the gate. The values of the time delay, pool area, and backwater length (pool area over water surface width) are shown in figure 3. The 2-to-3-km backwater length in this 12.6-km pool agrees with water surface profiles of the canal pool.

The second two pools did not exhibit this same behavior. While there was some delay in the initial change in water level at the downstream end, a line fitting the change in downstream water level at long times passed through the initial level at approximately the time of the flow change, indicating no time delay. In addition, the simulation results at various points along the canal pool showed large oscillations in discharge (fig. 4) and small oscillations in depth. These oscillation were the result of reflection waves that traveled up and down the pool and were damped by frictional resistance.

SRP has provided seven scenarios for testing the ability of the control scheme.

INTERPRETATION: The step change tests made by SRP were sufficient to verify the calibration of the MIKE-11 model by DHI. The MIKE-11 software can be programmed to test the controller on the Arizona Canal. The controller for the first two pools will include a time delay, while a low-pass filter will have to be added to the last two pools to insure stability. SRP's test scenarios appear to represent a good range of test conditions for the control scheme.

FUTURE PLANS: The programming for the user interface will be completed soon. The control model will be developed with the MATLAB routines. Following these two steps, the control scheme will be tested with the scenarios proposed by SRP. The suitability of this scheme will be analyzed under the limitations imposed by the Granite-Reef diversion. If the control scheme is successful, we will explore further application, either in real time or on additional canals within SRP's main canal network.

COOPERATORS: Jan Schuurmans, Delft U. of Technology, The Netherlands; Bob Gooch, Joe Rauch and Grant Kavlie, Salt River Project.

Table 1. Average pool properties for the Upper Arizona Canal.

Pool Number	Length	Bottom Width	Side-slope (horiz/vert)	Bottom Slope	Manning n	Maximum Capacity	Forebay Station ID	Forebay Target Depth
	(km)	(m)	(m/m)	(m/m)		(m^3/s)		(m)
1	12.7	18	1.4	0.00047	0.018	43	1-00.6	2.12
2	10.1	20	1.4	0.00035	0.018	36	1-01.9	1.65
3	4.1	20	1.3	0.00022	0.018	36	1-03.0	1.85
4	3.6	19	1.4	0.00020	0.018	36	1-05.0	1.85

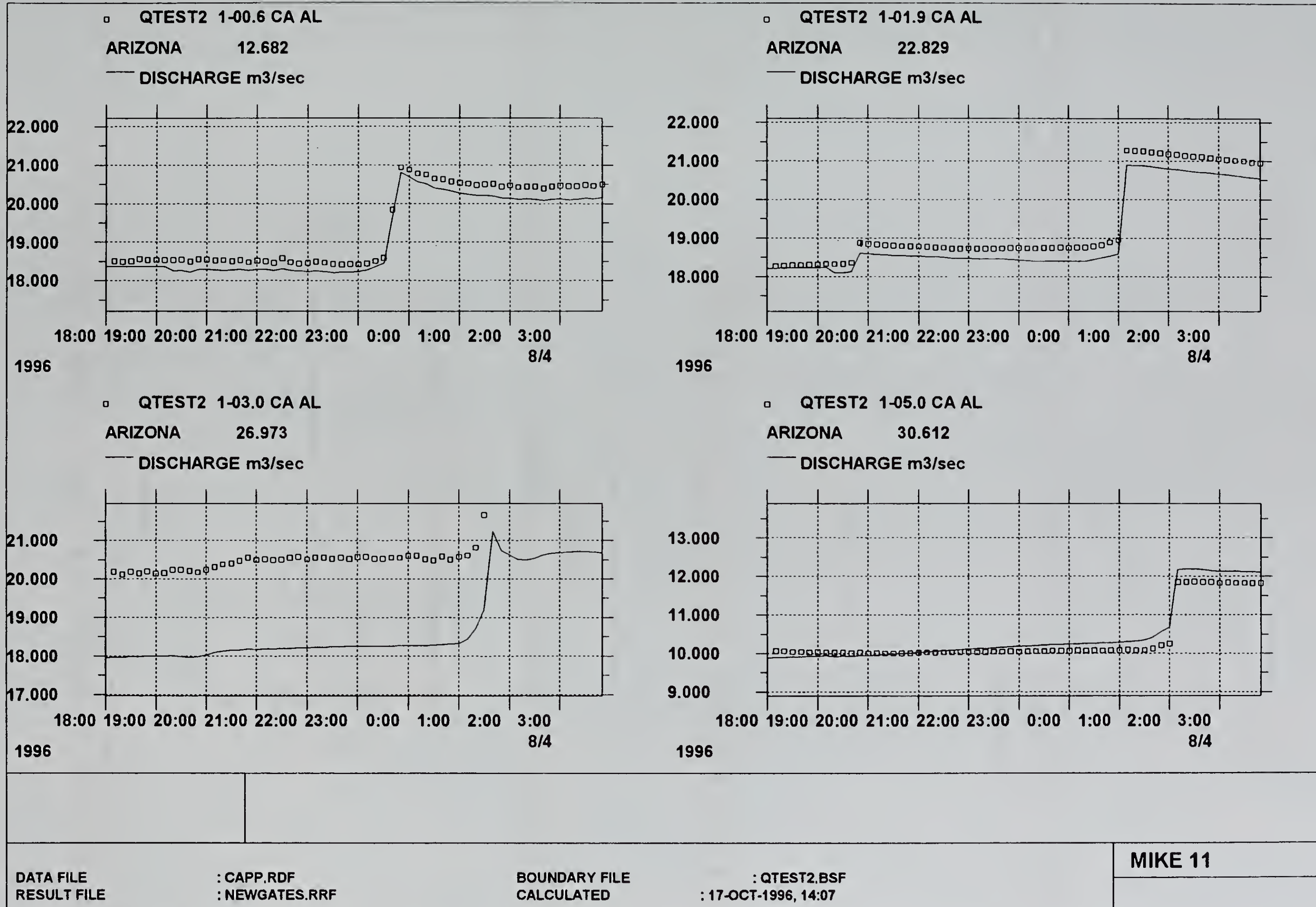


Figure 1. Comparison between observed (squares) and simulated (lines) flow rates for the first four pools of the Arizona Canal for a step change in inflow on April 7, 1996

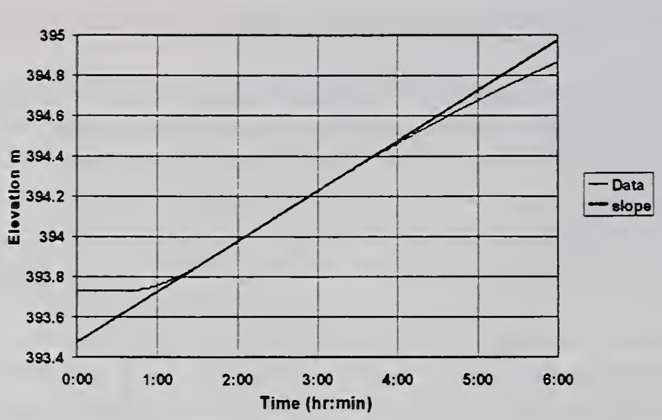


Figure 2. Response in water level at the downstream end of pool 1 on the Arizona Canal for a step change in inflow from 43 to 47.3m^3/s and no change in outflow (line of steepest slope is used to determine time delay and water surface of backwater area)

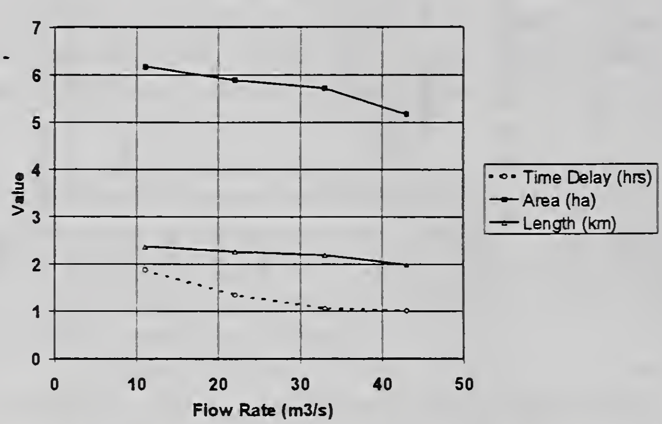


Figure 3. Time delay and backwater surface area and length for pool 1 of the Arizona Canal as a function of flow rate

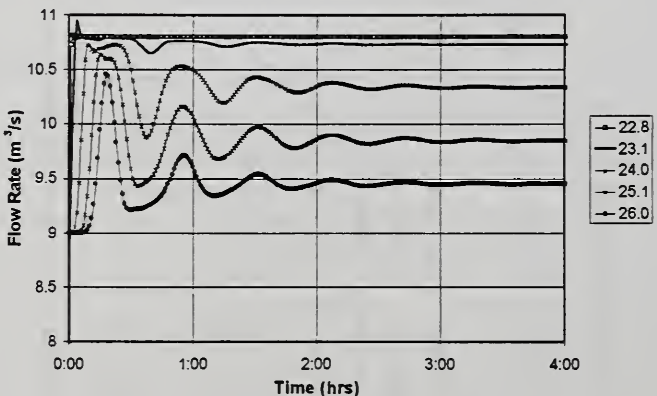


Figure 4. Flow rate over time within pool 3 of the Arizona Canal at various distances from the canal source (in km) for a change in inflow rate from 9 to 10.8 m^3/s and no change in outflow rate (9 m^3/s)

PROTECTION OF GROUNDWATER QUALITY

WATER REUSE AND GROUNDWATER RECHARGE

H. Bouwer, Research Hydraulic Engineer

PROBLEM: Increasing populations and finite water resources demand water reuse, as do increasingly stringent treatment requirements for discharge of sewage effluent into surface water. The aim of this research is to develop technology for optimum water reuse and the role that soil-aquifer treatment can play in the potable and nonpotable use of sewage effluent. Present focus in the U.S. is on sustainability of soil-aquifer treatment, particularly the long-term fate of synthetic organic compounds and disinfection byproducts in the underground environment. Fate of pathogens and nitrogen also needs to be better understood. In Third World countries, simple, low-tech methods must be used. Such methods will be applied to demonstration projects in the Middle East and North Africa under the White House Middle East Peace Initiative and the Technology for International Environmental Solutions (TIES) program of USDA and EPA.

APPROACH: Technology based on previous research at the USWCL and more recent research are applied to new and existing groundwater recharge and water reuse projects here and abroad. Main purposes of the projects range from protecting water quality and aquatic life in surface water to reuse of sewage effluent for nonpotable (mostly urban and agricultural irrigation) and potable purposes. A Southwest regional project is being developed to get more information about fate of synthetic organic compounds, nitrogen, and pathogens in the underground environment so that projects can be designed and managed (including pretreatment) to achieve desirable results, especially potable use of the water from the aquifer. The project will be set up for about four years and involves six existing field systems in Arizona and California, four universities, and numerous water districts, municipalities, and other participants and sponsors.

FINDINGS: Field and laboratory tests continue to show the usefulness of recharge and soil-aquifer treatment in water reuse. Main issues still are sustainability of soil-aquifer treatment and fate of recalcitrant organic compounds. Tests with experimental recharge trenches indicate acceptable recharge rates if suspended solids are effectively removed. Simplified procedures have been developed for cylinder infiltrometers to predict large-area, long-term infiltration rates from short-term tests with single cylinders. Also, simplified equations have been developed to predict long-term groundwater mound rises in recharge areas and where to locate recovery systems to prevent water logging in these areas.

INTERPRETATION: Results will be applied to existing and planned groundwater recharge and soil-aquifer treatment systems. Research proposals for funding by research foundations have been prepared. Participation was provided at various national and international conferences on groundwater recharge, soil aquifer treatment, and water reuse. Other national and international conferences are being planned and prepared.

FUTURE PLANS: Future plans primarily consist of initiating and coordinating research on groundwater recharge and water reuse issues by other institutions and responding to requests to write, speak, and advise.

PHYSICAL, CHEMICAL, AND BIOLOGICAL CHARACTERISTICS OF A SCHMUTZDECKE: EFFECTS OF SEEPAGE AND WATER TREATMENT IN WASTEWATER DISPOSAL FACILITIES

H. Bouwer, Research Hydraulic Engineer;
and M. Conklin, Professor of Hydrology

PROBLEM: Soil clogging occurs during artificial recharge and effluent disposal operations. Reduced infiltration and consequent ponding are largely attributed to development of a slime layer, or "schmutzdecke." The objectives of this project are to determine: (1) physical, chemical, and biological processes occurring in the schmutzdecke, (2) improvement of water quality after it has moved through the schmutzdecke (for example, effect of schmutzdecke on pathogen removal or nitrogen speciation), (3) how schmutzdecke should be managed for specific needs (in particular, to evaluate how schmutzdecke affects flow of essential nutrients: nitrogen, phosphorous, and potassium), and (4) how hydraulics affect schmutzdecke.

APPROACH: During the fourth year of this project, two soil columns (8.26 cm i.d. × 100 cm length) containing Sweetwater sandy loam were operated for study of surface clogging layers. One longer column (8.26 cm i.d. × 200 cm length) containing Agua Fria sand was also operated. Unchlorinated secondary effluent was applied to all columns in alternating (7 day wet/7 day dry) cycles. Studies were conducted to determine effects of temperature and levels of molecular oxygen on organic removal. Algal mats were sampled and analyzed. Operation of the columns was concluded this year. Column breakdown studies of the 100-cm columns included enumeration of soil heterotrophic bacteria and soil organic carbon content (f_{oc}) as a function of depth.

A program of consolidation and hydraulic conductivity testing was conducted with the intent of quantifying the mechanical and hydrologic characteristics of the clogging layer and its individual components. This program included tests of actual clogging layers, as well as tests on some of the individual constituents, such as soil and algae. Clogging layer specimens were obtained from several effluent infiltration column experiments that had been operated for nearly two years as a part of this study. The clogging layer samples from the infiltration columns were subdivided vertically into individual specimens for testing. Each specimen represented a two-centimeter increment of depth below the column surface (pond base). For each specimen, hydraulic conductivity and consolidation tests were performed, and total organic content was determined.

FINDINGS AND INTERPRETATION:

Organic-related studies-- Numbers of culturable heterotrophic bacteria were approximately two orders of magnitude higher (1.1×10^8 to 8.8×10^8 cells/g soil) in the top 2 cm of soil (fig. 1), indicating that this zone is responsible for a significant portion of the biologically-mediated removal of organics occurring in the soil column. Soil f_{oc} followed a similar distribution: at the surface, f_{oc} ranged from 11.6 to 12.7%; below a depth of 12 cm, f_{oc} ranged from 0.04 to 0.10% (fig. 1). The two-meter column was operated for 15 alternating wet/dry cycles. Organics (DOC-dissolved organic carbon, UV-254) removal efficiencies were not enhanced during percolation through the second meter of soil, relative to removals observed for previous studies using 100-cm columns containing the Agua Fria sand. Measurements of molecular oxygen along column profiles indicate that O_2 concentrations are reduced to microaerobic levels (< 1 mg/L) within the first 24 hours of column startup during wetting periods (fig. 2). Preliminary results show that, contrary to expectations, organic carbon removal efficiencies are not O_2-limited, suggesting that another reaction (e.g., nitrogen fixation) is depleting O_2 . Soil temperature (15, 25, 30°C) was used as a independent variable for a single column containing the Sweetwater sandy loam. At the lowest temperature tested (15°C), hydraulic conductivity of the surface clogging zone was not reduced during a seven-day wetting cycle; infiltration remained constant at the applied hydraulic loading rate of 3.3 m/day. Although previous work has shown that biological activity is responsible for up to 80% of DOC removal, there did not appear to be a significant relationship between the selected soil temperatures and removal efficiency of DOC. Identification of algal species was performed by the Environmental Research Laboratory of The University of Arizona for samples obtained from surface clogging zones of columns and the Sweetwater Underground Storage and Recovery Facility. Multiple species of blue-green algae, green algae, diatoms, and Euglenoids were identified. Filamentous species predominated in both field and laboratory samples.

Compressibility Studies--Results from the consolidation and hydraulic conductivity testing on specimens of mixed-culture algae are shown in figure 3. An effective stress in the range of 1 to 10 kPa was found to be of greatest interest in these studies because this corresponds to typical SAT range of water depth of 15 to 60 cm. Clearly, the loose algae can compress under the expected seepage gradients, resulting in hydraulic conductivity values significantly less than that expected for the sandy and silty soils. The hydraulic conductivity of the algae specimens was approximately equal to that of the Agricultural Field Clay at an effective stress of only 3 to 4 kPa.

The results of the hydraulic conductivity and consolidation testing for the Sweetwater soil and filtered secondary effluent column studies are shown in figure 4. In general, the lowest conductivities and highest organic content were found in the top 2 cm of specimen. In all cases considered, over a range of void ratios, and thereby effective stresses, the conductivity of the upper specimen is consistently and substantially less than that of specimens from other depths in the soil profile, all of which were found to have approximately equal conductivity.

These tests indicate that the algae are a very significant contributor to the reduction in hydraulic loading rates caused by the formation of the clogging layer. Further, it appears that compression of the algae resulting from seepage gradients can be significant for effluent depths in the range of several centimeters to meters, as normally used in SAT operations. From an operational perspective, the depth of water was found to have marked effect on surface clogging, and since the desired depth influences the geometry and layout of the basins, this influences the design process as well. The nature of the clogging is strongly related to site and climatic conditions. In an environment that is rich in algae and/or suspended solids, increasing the depth of effluent can decrease infiltration rates by seepage-force-induced compression of the clogging material. Under other conditions, increasing the pond depth was found to increase the rate of infiltration. Water depth is also significant in that it influences the average hydraulic retention time of the basin, which in turn impacts the growth of algae.

FUTURE PLANS: Future studies will include further analysis of temperature and oxygen effects on SAT performance. Upcoming field studies at the Sweetwater Wetlands will include measurement of development rate of clogging zones in an unlined, free-water-surface wetland receiving secondary effluent.

COOPERATORS: Martha Conklin, Assistant Professor; L.G. Wilson, Hydrologist; Robert Arnold, Associate Professor; C.P. Gerba, Professor; Kevin Lansey, Assistant Professor; David Quanrud and Katanya Miles, Research Assistants; University of Arizona; Sandra Houston, Associate Professor; Peter Fox, Assistant Professor; and Peter Duryea, Research Associate; Arizona State University.

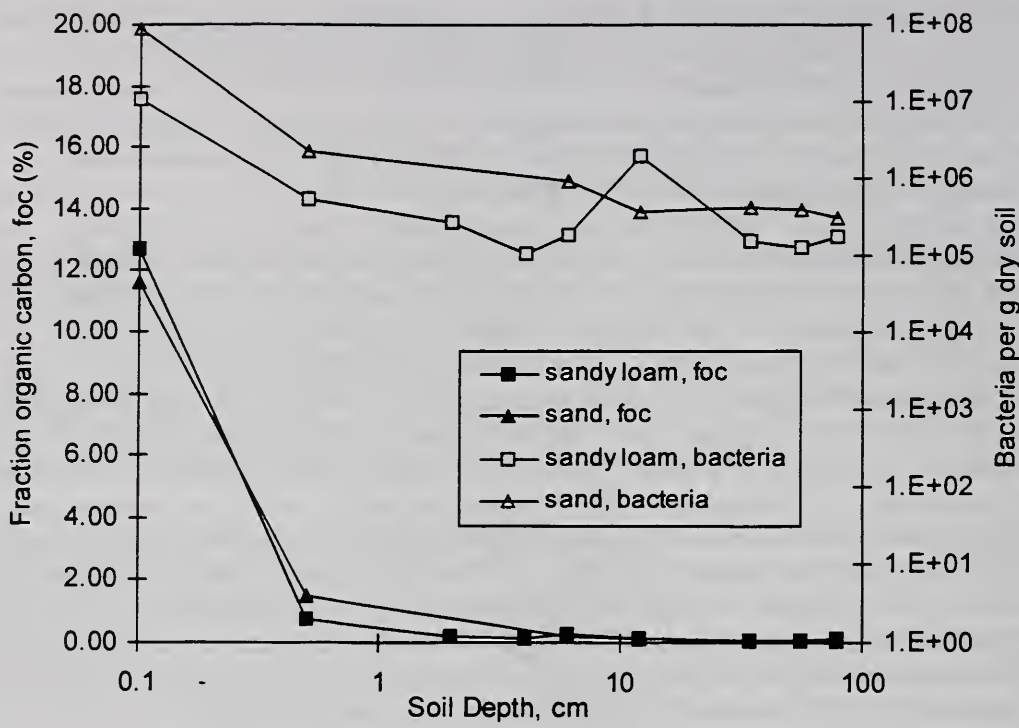


Figure 1. Heterotrophic bacteria and f_{oc} as a function of soil depth in 1-m columns containing Agua Fria sand and Sweetwater sandy loam.

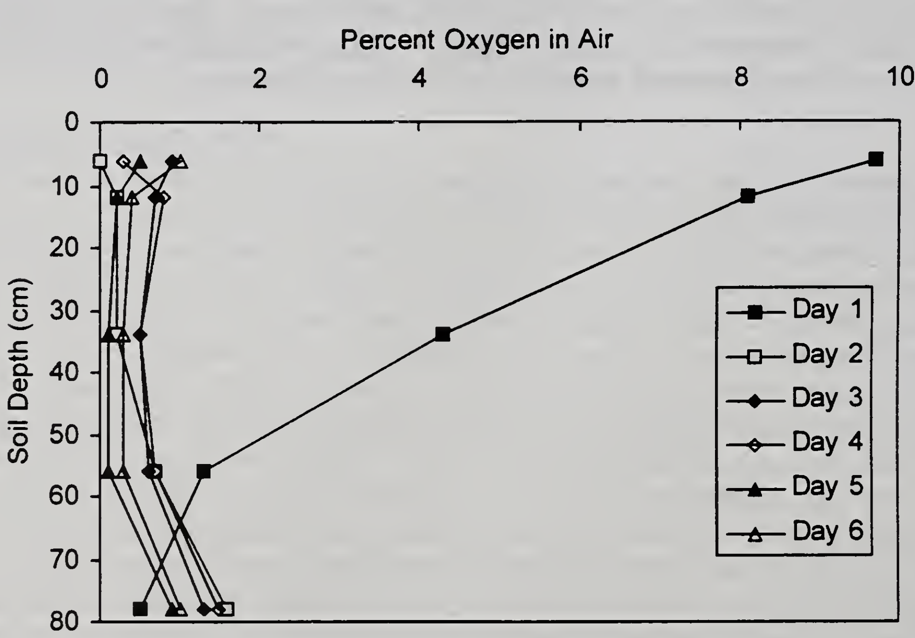


Figure 2. Gas phase molecular oxygen as a function of soil depth during a 7-day wetting period for a 1-m column containing Sweetwater sandy loam.

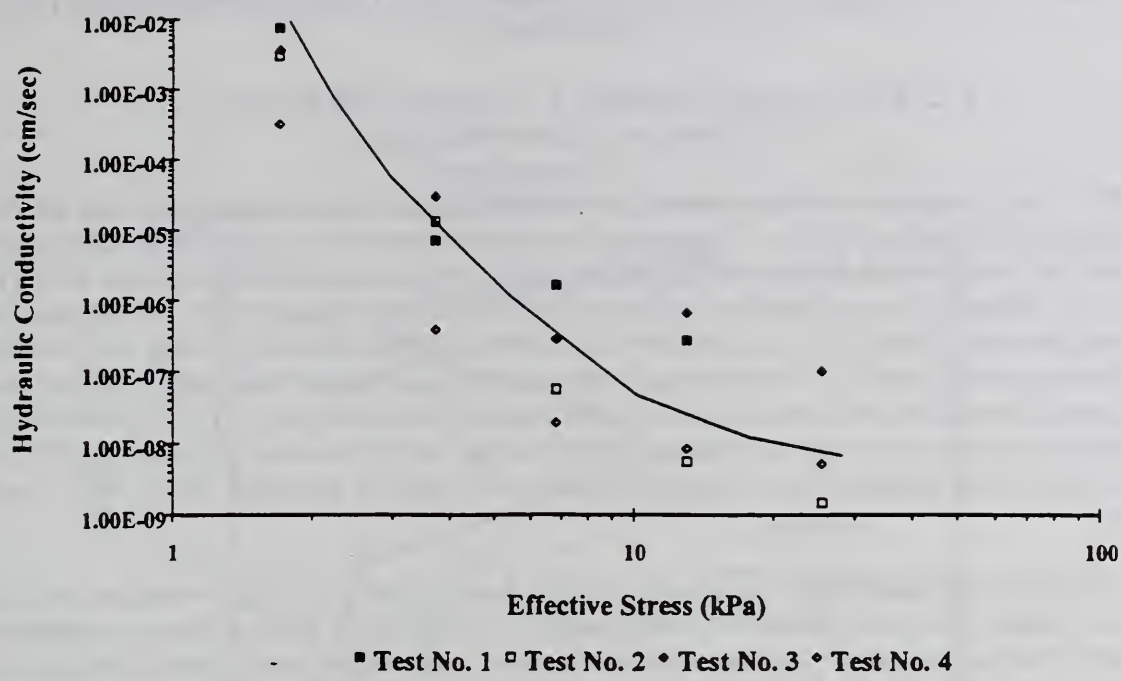


Figure 3. Compression and hydraulic conductivity tests on mixed culture algae.

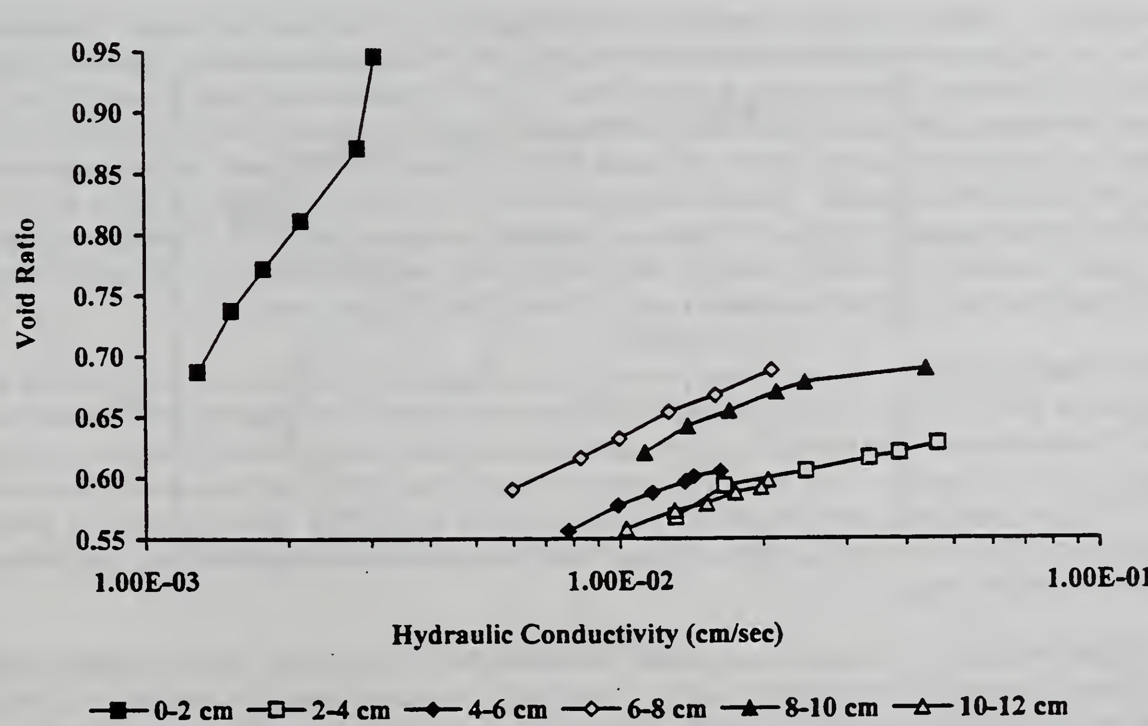


Figure 4. Compression and hydraulic conductivity tests on clogging layer specimens (Sweetwater soil and filtered secondary effluent).

NITROGEN FERTILIZER AND WATER TRANSPORT UNDER 100% IRRIGATION EFFICIENCY

R.C. Rice, Agricultural Engineer; F.J. Adamsen, Soil Scientist; and
D.J. Hunsaker, Agricultural Engineer

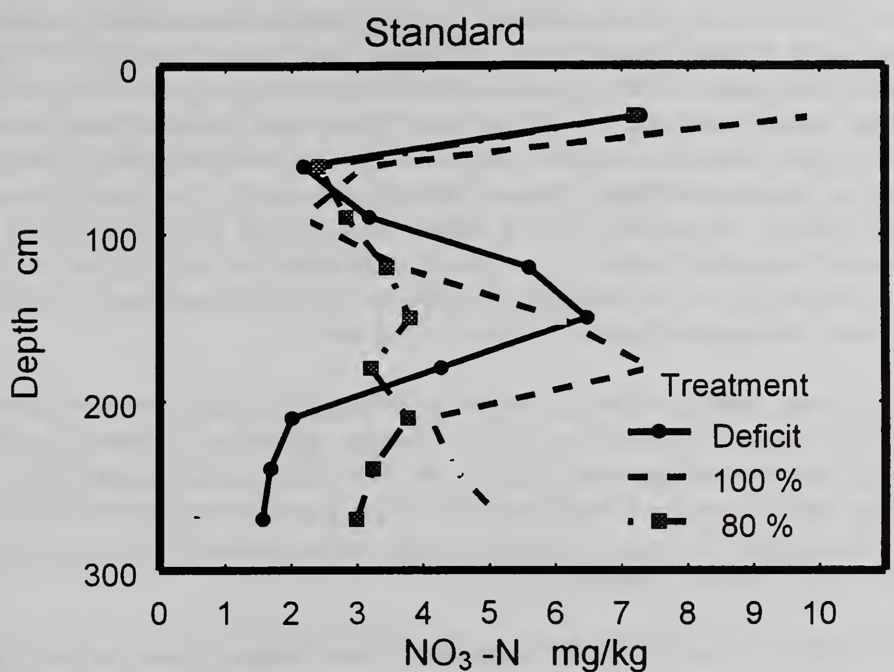
PROBLEM: The rising trend in nitrate levels of groundwater suggests that nitrogen fertilizers are frequently being transported beyond the root zone. Improving management practices in irrigated agriculture may lead to better control of nitrogen contamination of the groundwater. Using feedback techniques such as soil and crop nitrogen status and more frequent fertilizer applications with smaller application rates are suggested as better management practices. Previous studies indicated that 100% irrigation efficiency during the growing season limited the transport of nitrogen to the vadose zone. Preferential flow and spatial variability, however, may cause water and nutrient losses from the root zone even under ideal management conditions. The objective of this study is to determine the movement of water and nitrogen fertilizer in the soil profile when irrigating at 100% irrigation efficiency and develop associated Best Management Practices (BMPs) to protect the quality of underlying groundwater.

APPROACH: The field studies were expanded in 1996 to include alfalfa. Nitrogen management on alfalfa is different from wheat and cotton because of alfalfa's ability to fix nitrogen, making nitrogen applications only rarely needed. Water movement in the soil profile was characterized with soil water content and tracer analysis. Evapotranspiration was estimated from soil water depletion data and energy balance techniques using meteorological data collected at the site. Irrigation scheduling was determined using a soil water balance method. Experimental treatments on the alfalfa included only irrigation treatments. The treatments were (1) 100% irrigation efficiency, (2) 80% irrigation efficiency, and (3) with 20% deficit irrigation. The studies on cotton using level basin flood irrigation were completed in 1995.

FINDINGS: Analysis of the soil samples for the cotton studies have not been concluded. Preliminary analyses of the data indicate similar results as in previous years (fig. 1). The nitrate concentrations were greatest near the surface and decreased to lower values at 60 to 90 cm. A nitrate peak occurred at depths of 150 to 180 cm. The source of the nitrate peak was residual nitrogen in the profile that was leached by early irrigations. As in previous years, less nitrate was leached below 100 cm at 100% irrigation efficiency and deficit irrigation for both the standard and BMP treatments. The deficit irrigation treatment had the least NO_3-N below the root zone. The BMP treatments showed lower levels of nitrate in the deficit irrigation and 100% efficiency treatments. At 80% efficiency, however, the BMP treatment was similar to the standard treatment. The alfalfa plots have been established and the irrigation treatments started. No soil samples have been taken.

INTERPRETATION: Management practices such as applying fertilizer at more frequent intervals and irrigating at 100% efficiency during the growing season may result in less leaching of the nitrate below the root zone. Nitrate levels increase during the fallow period probably from mineralization of organic nitrogen. Existing nitrate in the soil profile at the start of the growing season may be leached when nitrate is moved below the effective root zone from early irrigations before the crop is established. Best management practices need to consider pre-plant soil nitrogen status, timing of fertilizer and irrigation applications, and build-up of nitrate during the fallow season.

FUTURE PLANS: Nitrogen management on alfalfa will be continued. Nitrate leaching under different irrigation methods (drip or sprinkler) will be investigated. Fertilizer application methods such as chemigation (applying with irrigation water), broadcast, side dressing, and foliar spray will be investigated.



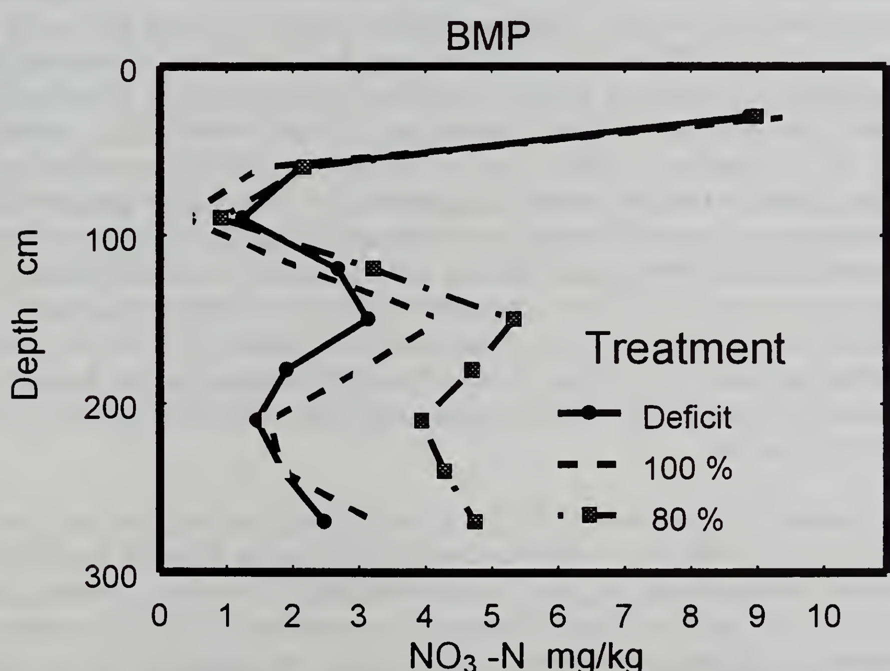


Figure 1. Nitrate - N with depth for standard and BMP treatments at 100% irrigation efficiency, 80% irrigation efficiency, and 20% deficit irrigation.

EVALUATION OF RAPE AND CRAMBE AS POTENTIAL WINTER CROPS TO REDUCE NITRATE ACCUMULATION IN THE SOIL

F. J. Adamsen, Soil Scientist; W. L. Alexander, Agronomist; and R. C. Rice, Agricultural Engineer

PROBLEM: Formation of nitrate during fallow periods in irrigated cotton rotation systems can lead to leaching of nitrate to groundwater when preplant irrigations are applied to make the soil suitable for tillage operations. One solution to this problem is growing a winter crop that utilizes residual nitrogen and nitrate mineralized during the winter. Because of the cost of water, any crop grown in the winter under irrigated conditions must have an economic return in order to gain producer acceptance and a crop must be found that can be planted after cotton is harvested in the fall and can be harvested before cotton is planted in the spring. Two crops that may meet these constraints are rape and crambe. Industrial rape and crambe both contain erucic acid which has industrial potential, and Canola types of rape are valuable as a source of unsaturated cooking oil. Both of these crops are short, cool season crops that may meet the short growing season requirement and have a significant nitrogen requirement that would take advantage of residual nitrogen in the soil.

APPROACH: Research is being conducted through a series of field experiments to evaluate yield potential and planting and maturity dates of rape and crambe. One variety of crambe, one variety of spring type industrial rape, and ten varieties of spring Canola type of rape were planted in the 1995-1996 growing season in 2 x 12.2-m plots on three planting dates from early November to mid December. Row spacing was 0.25 m. The spring industrial and two of the spring Canola types of rape are campestra types of the species *Brasica rapa,* while the other Canola types of rape are from the species *Brasica napus*.

FINDINGS: In the 1995-1996 as in the 1994-1995 crop year, rodent damage to the Canola types of rape was minimized through an aggressive rodent control program. Harvest dates varied from April 16 to 30 (table 1). The starting harvest date was later than in 1994 or 1995, but the final harvest was earlier. The range of harvest dates was narrowed as the planting date became later. All lines were harvested on the same day for the third planting date. For the first two planting dates, R-500 was the earliest maturing Polo and Oscar, the earliest *Brasica napus* type. The range of harvest dates was narrower in 1995-1996 than in previous years. Tobin and CSU-045 had serious lodging problems. After the plants lodged a second set of flowers were formed, which delayed their maturity and reduced yields of these two varieties. Except for Crambe, yields decreased as the planting date became later. This probably is due to the temperature being too high at flowering for adequate pollination. Oil content of the rapeseed varieties was over 40% while the oil content of Crambe was between 30 and 40% (fig. 1). There was no consistent relationship between planting date and oil content. Flowering pattern of Crambe was different from all of the rape varieties (fig. 2). In rape, the number of days to flowering decreased as the planting date was later, but in Crambe, the number of days to flowering was nearly identical for the first and third planting dates, and the second planting date was slower. This indicates that a different mechanism drives flowering in the two species. The difference in flowering pattern between rape and Crambe is also reflected in the difference in yield pattern between the two species.

INTERPRETATION: Crambe yields were over 2000 kg ha^{-1} for all three planting dates and over 3000 kg ha^{-1} for the first and third dates. The earliest harvest date was later in 1996 than in either of the previous years. The delay in harvest date also would delay planting of cotton, which would result in marginal planting dates for cotton. Yields of Canola above 2500 kg ha^{-1} are considered economical in the southeastern U.S. We were well above that for several varieties, indicating that Canola production in rotation with cotton is potentially economically viable in the desert Southwest as a winter crop. The *Brasica rapa* varieties did not mature earlier than the *Brasica napus* as hoped. This was due to problems with lodging, which resulted in a second flower set.

FUTURE PLANS: In 1997, evaluation of rape and crambe will be continued. An additional earlier planting date will be added. Current planting dates indicate how late the crop can be planted but not how early. Irrigation and other agronomic studies will be conducted to make the yields of winter crops economical. Additional studies will be initiated to determine the water and fertilizer requirements of rape and crambe under local conditions. The results of the planting date by variety trial and water use and fertility trials will be used to develop a rotational

system with cotton that will provide year-round cover on the soil and should improve year-round nitrogen management.

COOPERATORS: Paul Raymer, Coastal Plain Experiment Station, Tifton, Georgia; Larry Sernyk, Agrigenetics, Madison, Wisconsin; Jennifer Mitchell Fetch, University of North Dakota, Fargo, North Dakota; Duane Johnson, Colorado State University, Fort Collins Colorado.

Table 1. Rape and Crambe yields in the 1995-1996 crop year at Maricopa Agricultural Center. All data are based on replication.

Variety	Planting Date	Harvest Date	Yield kg ha^{-1}	Planting Date	Harvest Date	Yield kg ha^{-1}	Planting Date	Harvest Date	Yield kg ha^{-1}
R-500	3 Nov	16 Apr	3395	24 Nov	22 Apr	2498	15 Dec	30 Apr	2170
Crambe	3 Nov	24 Apr	3192	24 Nov	25 Apr	2423	15 Dec	30 Apr	3131
Polo	3 Nov	19 Apr	2546	24 Nov	23 Apr	2216	15 Dec	30 Apr	1790
Cyclone	3 Nov	24 Apr	1993	24 Nov	23 Apr	1739	15 Dec	30 Apr	1170
A112	3 Nov	24 Apr	1603	24 Nov	25 Apr	1382	15 Dec	30 Apr	969
RP04-2	3 Nov	24 Apr	1701	24 Nov	25 Apr	1175	15 Dec	30 Apr	1048
Oscar	3 Nov	19 Apr	2312	24 Nov	25 Apr	1410	15 Dec	30 Apr	1512
Westar	3 Nov	22 Apr	2068	24 Nov	25 Apr	1592	15 Dec	30 Apr	1556
CSU-045	3 Nov	19 Apr	1911	24 Nov	25 Apr	1409	15 Dec	30 Apr	772
Hyola-029	3 Nov	23 Apr	2829	24 Nov	25 Apr	2549	15 Dec	30 Apr	1491
ST-011	3 Nov	22 Apr	2499	24 Nov	29 Apr	1324	15 Dec	30 Apr	1406
Tobin	3 Nov	24 Apr	1452	24 Nov	23 Apr	1355	15 Dec	30 Apr	907

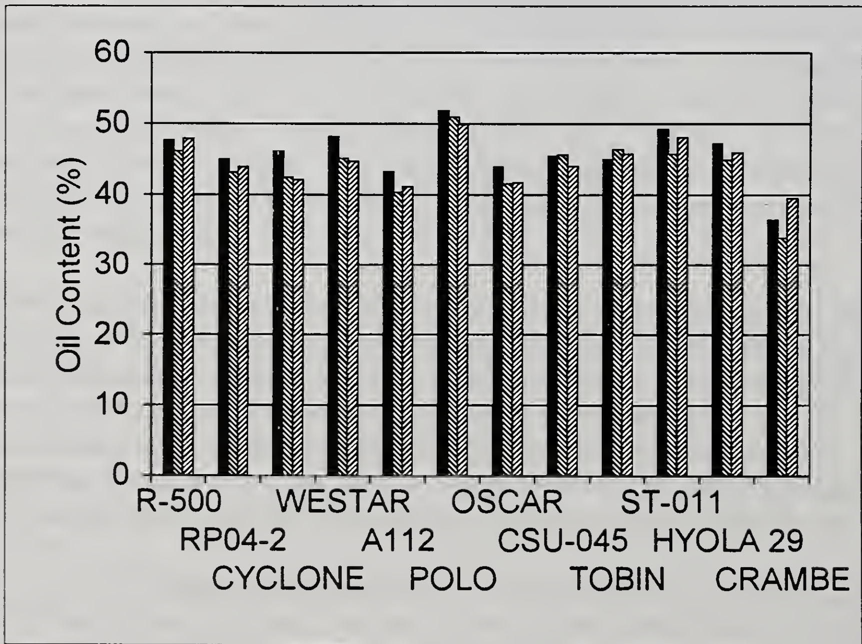


Figure 1. Oil content of rape and crambe from three planting dates in the fall of 1995.

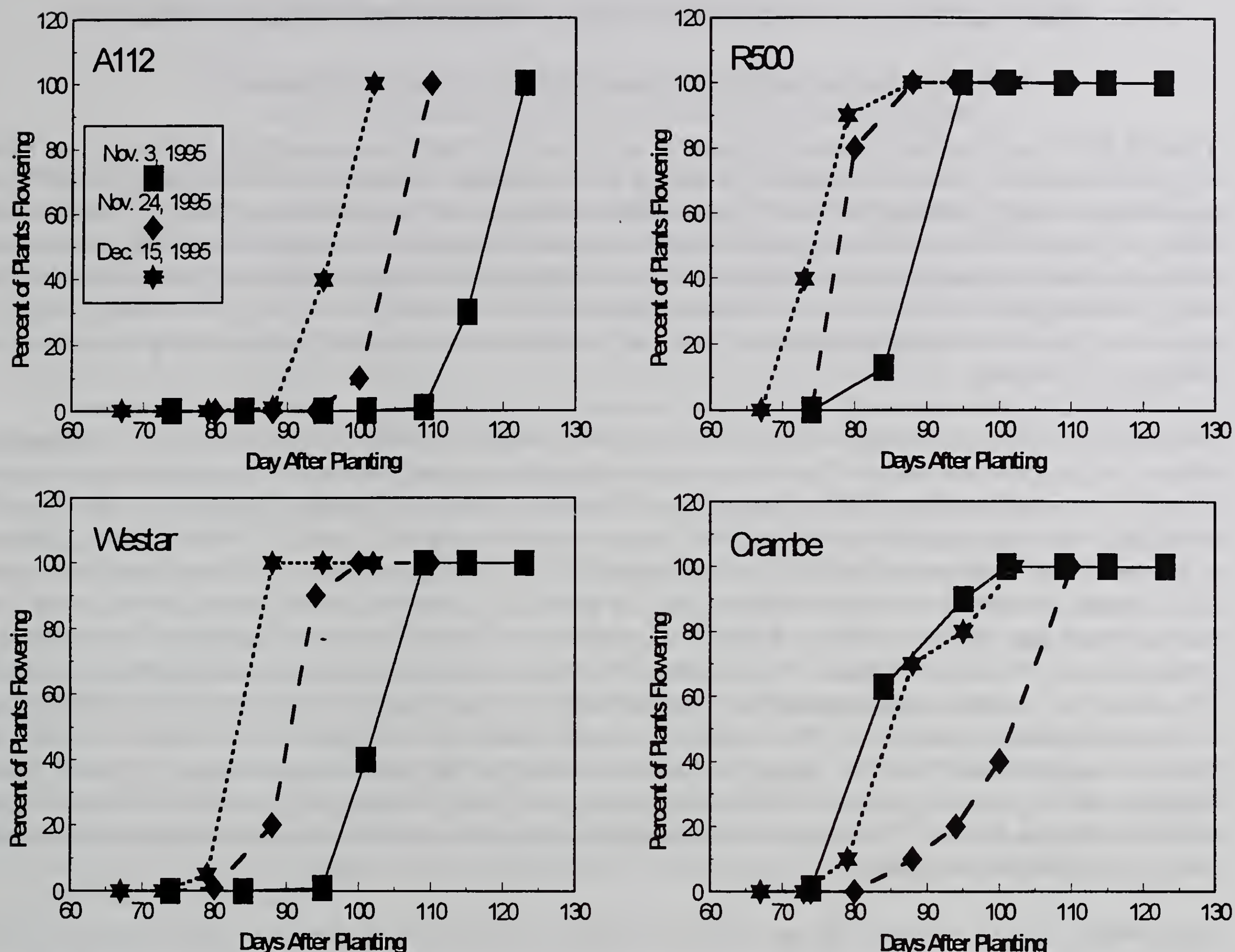


Figure 2. Days to full flowering for three varieties of rape and for Crambe for three planting dates.

ASSESSMENT OF NITRATE LEACHING UNDER COMMERCIAL FIELDS

F. J. Adamsen, Soil Scientist; and R. C. Rice, Agricultural Engineer

PROBLEM: Application of excess nitrogen to crops such as cotton and subsequent application of excess irrigation water can result in movement of nitrate to groundwater. When nitrate is found in groundwater, agriculture is usually assumed to be the source of the contamination. A number of surveys of Midwest fields indicate that farm practices are responsible for at least part of the nitrate that finds it way into groundwater. Under irrigated conditions, nitrate leaching is a function of irrigation efficiency and spatial variability as well as fertilizer management, which makes assessment of the problem more complex. The purpose of this study is to determine if nitrate is leached below the root zone and the relationship of nitrate leaching to irrigation efficiency and spatial variability.

APPROACH: Research is being conducted by taking soil samples from commercial fields before planting and after a crop has been harvested. Three transects were taken across each field with five samples taken in each transect. Spacing of samples along the transect was based on the length of the run. The first sample was taken 10% of the run length from the top of the field. The next four samples were taken 20% of the run length apart. A 2-m by 2-m area was amended with KBr before the start of the growing season so that the depth of penetration of that season's irrigation water can be determined. The positions on a transect were numbered from one to five, starting at the upper end of the field. Samples were taken to a depth of 270 cm and analyzed for ammonium, nitrate, bromide, chloride, and texture. Water samples were taken from each irrigation and the concentrations of chloride, nitrate, and ammonium determined. Chloride values in the soil will be used to provide a crude estimate of actual evapotranspiration. In 1996, samples were taken from one field planted to continuous cotton. The producer changed from 40-inch row spacing to 32-inch rows this year and planned to make smaller, more frequent irrigations by irrigating every other row. The field is sloping with runoff. Flumes were installed to measure water entering and leaving the field. Automated data collection systems were operated during each irrigation during the 1996 growing season for cotton.

FINDINGS: At this time, the crop has not been harvested, so no data is available on nitrate movement under the new system of irrigation used by the producer. Tentative analysis of the irrigation practices used indicates that irrigation frequency was the same as in previous years. Total irrigation has not been computed at this time, so changes in irrigation amounts cannot be calculated.

INTERPRETATION: Changing the row spacing did not appear to change the frequency of irrigation on the field being studied. It remains to be seen if the change in planting pattern will affect the amounts of irrigation water applied or the amount of nitrate movement from the root zone.

FUTURE PLANS: Samples will be taken from the study site after the crop is harvested. The amounts of water applied will be determined and compared with the results from prior years. Additional sites using different crop rotations and irrigation methods will be sought for study.

COOPERATORS: Buddy Ekholt, Pinal County Irrigation Management Program; T. L. Thompson, University of Arizona, Dept. of Soil and Water Science.

SIMULATING THE TRANSPORT OF CHEMICALS IN SURFACE-IRRIGATION FLOWS

T. S. Strelkoff, Research Hydraulic Engineer; F. J. Adamsen, Soil Scientist;
and A. J. Clemmens, Supervisory Research Hydraulic Engineer

PROBLEM: Irrigation management influences the quality of both surface and groundwater supplies. Chemigation introduces agricultural chemicals into the irrigation water. Initially clean irrigation water picks up agricultural chemicals and naturally occurring minerals, some toxic, from the surface of fields and from contact by percolation through the porous soil medium. Nitrogen, chlorinated organic compounds, and heavy metals, for example, brought to farm fields in the course of agricultural operations and naturally occurring chemicals, such as selenium, can be transported to surface or subsurface water supplies by the movement of irrigation water, to the detriment both of human consumers of the water resource and wildlife dependent on these bodies of water.

The transport, transformation, and ultimate fate of chemical components of the irrigation water depend on the quantities of water with dissolved chemicals running off the ends of the fields and the quantities of sediment with adsorbed chemicals entering into drainage ditches and canals, as well as the quantities of water that percolate through the soil, entraining or losing chemicals to adsorption on the soil particles, and entering eventually either a groundwater aquifer or a river fed from groundwater seepage. The chemical and physical reactions between the water, the soil medium, and the particular chemicals involved significantly influence the transformation and ultimate fate of the chemical constituents. *Fingering* of the water front advancing downward through the soil medium occurs both as the result of nonhomogeneous soil, with worm and root channels, and layering of soils with a layer of low permeability overlying one of greater permeability. This results in more rapid transport of waterborne constituents to the groundwater table than with reasonably homogeneous soils.

The goal of this research effort is a predictive tool, i.e., a computer model, capable of simulating the transport and fate of sediment and chemicals, and thus capable of predicting the environmental response of a given agricultural field and its geologic site to one or another irrigation-management practice. Computer simulations would allow comparisons among various trial management modes in a program to seek optimum solutions. Recommendations could then be made on the basis of environmental considerations as well as upon water conservation and crop yield.

APPROACH: Several different problems comprise the subject of investigation: (1) transport of a contaminant by irrigation water from a contaminated soil-surface layer to stream flow and to the groundwater via deep percolation; (2) the distribution of a chemical introduced nonuniformly with the irrigation inflow, e.g., a pulse of chemical introduced at some time after the start of irrigation; (3) sediment entrainment and deposition in surface-irrigated fields; (4) adsorption/desorption of chemical constituents on the sediment particles. Earlier work, referenced in previous reports, centered on development of a plane two-dimensional (longitudinal and vertical) mathematical simulation, coupling a solution of the turbulent Navier-Stokes equations augmented with a two-equation turbulence model in the surface stream to a solution of the equations for unsaturated flow in the underlying soil. This model is expected to provide a theoretical base for more approximate, more practical simulations (see report, Surface Irrigation Modeling in this volume). Sediment discharge from irrigated fields, of interest in itself, as well as providing a vehicle for chemical transport, is viewed as the resultant of soil erodibility on the one hand and irrigation-water transport capacity on the other. Ultimately, the features of adsorption and desorption of chemicals on the surfaces of suspended and rolling sediments can be added. A physical model with a graded sand bed is to be used for verification of the mathematical model.

FINDINGS: No significant findings have been established since the last report, with the conclusion of the cooperative agreement supporting the development of the turbulent Navier-Stokes simulation model. Preliminary review of the irrigation-induced erosion component in the USDA WEPP (Water Erosion Prediction Project) model has begun.

FUTURE PLANS: The timing of future plans depends upon the extent of funding available. A soil-erosion component is anticipated for the one-dimensional surface-irrigation-simulation model. The existing turbulent Navier-Stokes model should be exercised over a range of practical conditions to establish and strengthen its reliability. Specific chemical constituents to be incorporated into the model should be selected, along with

currently available figures on reaction kinetics. The physical flume and mathematical model should be operated under mutually equivalent conditions to test the various model assumptions, establish appropriate values for numerical solution parameters, and verify performance. Simplified treatments of chemical transport and fate should be added to the one-dimensional surface-irrigation-simulation model.

COOPERATORS: M.L. Brusseau, P.M. Waller, The University of Arizona; N.D. Katopodes, University of Michigan.

PLANT GROWTH AND WATER USE AS AFFECTED BY ELEVATED CO_2 AND OTHER ENVIRONMENTAL VARIABLES

PROGRESS AND PLANS FOR THE FREE-AIR CO_2 ENRICHMENT (FACE) PROJECT

B. A. Kimball, Soil Scientist; P. J. Pinter, Jr., Research Biologist; G. W. Wall, Plant Physiologist; R. L. LaMorte, Civil Engineer; D. J. Hunsaker, Agricultural Engineer; F. J. Adamsen, Soil Scientist; T. J. Brooks, Research Technician; and F. S. Nakayama, Research Chemist

PROBLEM: The CO_2 concentration of the atmosphere is increasing and expected to double sometime during the next century. Climate modelers have predicted that the increase in CO_2 will cause the Earth to warm and precipitation patterns to be altered. This project seeks to determine the effects of such an increase in CO_2 concentration and any concomitant climate change on the future productivity, physiology, and water use of crops.

APPROACH: Numerous CO_2 enrichment studies in greenhouses and growth chambers have suggested that growth of most plants should increase about 30% on the average with a projected doubling of the atmospheric CO_2 concentration. However, the applicability of such work to the growth of plants outdoors under less ideal conditions has been seriously questioned. The only approach that can produce an environment as representative of future fields as possible today is the free-air CO_2 enrichment (FACE) approach.

Therefore, from December 1993 through May 1994 two FACE experiments were conducted on wheat at ample and limiting levels of water supply, with about 50 scientists from 25 different research organizations in eight countries participating. About 20 papers have been published or are in press from these experiments, and several more are being prepared.

However, one of the greatest uncertainties in determining the impact of global change on agricultural productivity, as well as natural ecosystems, is the response of plants to elevated CO_2 when levels of soil nitrogen are low. Therefore, we conducted another FACE Wheat experiment at ample and limiting supplies of soil nitrogen from December 1995 through May 1996. Funded by the Department of Energy through a grant to the University of Arizona, U.S. Water Conservation Laboratory personnel were major collaborators on the project and provided management support. A new feature of the 1995-6 experiment was that blowers were added to the control plots to make them more like the FACE plots, and there were two "ambient" plots with no blowers. Thus, we had an ancillary experiment to evaluate the effect of these blowers on crop growth in addition to the main experiment of determining the interactive effects of varying CO_2 and soil N on wheat response.

Similar to the previous experiments, measurements included: leaf area, plant height, above-ground biomass plus roots that remained when the plants were pulled, apical and morphological development, canopy temperature, reflectance, chlorophyll, light use efficiency, energy balance, evapotranspiration, soil and plant elemental analyses, soil water content, photosynthesis, respiration, stomatal conductance, antioxidants, stomatal density, decomposition, grain quality, video observations of roots from minirhizotron tubes, soil CO_2 and N_2O fluxes, and changes in soil C storage from soil and plant C isotopes. In addition, soil cores and leaf samples were obtained and are being stored frozen for later analyses of root biomass and soil nitrogen, photosynthetic proteins, and carbohydrates. Fortunately, we have recently been awarded a grant from an NSF/DOE/NASA/USDA program (TECO) plus ARS Temporary Global Change Funds, which will enable us to hire the personnel to do these analyses during the next year.

All of the data will be assembled in a standard format for validation of wheat growth models. Several collaborating wheat growth modelers plan to utilize the data.

FINDINGS: Analyses of the data the 1995-6 FACE Wheat Experiment are underway as reported by Pinter et al., Wall et al., Brooks et al., Hunsaker et al., Nakayama, and Kimball et al., in this volume. Briefly, the preliminary results indicate that under the high nitrogen treatment, wheat grain yields were increased about 15% by FACE at 200 μmol/mol above ambient, which is somewhat more than the 10% increase obtained in the two prior experiments. At low nitrogen, yields increased about 12%. The low nitrogen treatment reduced yields about 20% at both levels of CO_2. Water use was unchanged, as indicated by water balance measurements.

INTERPRETATION: These data plus those from our prior FACE wheat experiments suggest that with ample water, wheat production is likely to increase 10-15% by an increase in atmospheric CO_2 levels to 200 μmol/mol above current levels (about 370 μmol/mol). Moreover, in contrast to many chamber studies, our results suggest that the yield increases will occur even at low levels of soil nitrogen characteristic of the agriculture in developing countries and most natural ecosystems. Irrigation requirements may be unchanged or slightly reduced for future wheat production, provided climate changes are minimal.

FUTURE PLANS: From December 1996 through May 1997, the FACE Wheat Experiment will be repeated at ample and limiting soil nitrogen. Discussions are underway about the crop to propose for study in the next funding cycle, with sorghum being the front runner at this time. If sorghum is selected, and if funding can be obtained, the first FACE sorghum experiment would probably be conducted during the summer of 1998.

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EFFECTS OF FREE-AIR CO2 ENRICHED (FACE) AND TWO SOIL MOISTURE REGIMES ON VERTICAL AND HORIZONTAL DISTRIBUTION OF ROOT LENGTH DENSITY, SURFACE AREA, AND DENSITY OF SPRING WHEAT

G. W. Wall, Plant Physiologist; F. Wechsung, Plant Physiologist; G. Wechsung, Soil Scientist; B. A. Kimball, Supervisory Soil Scientist; Th. Kartschall, Physicist; P. J. Pinter, Jr., Research Biologist; and R. L. LaMorte, Civil Engineer

PROBLEM: Root systems are generally deeper and more branched (occupy a greater soil volume), have increased growth rates, altered morphology, different distribution patterns between adjacent plants, altered carbon economy and sorption kinetics in plants grown in elevated atmospheric CO_2 (Ca) compared with ambient-Ca grown plants (Rogers and Runion, 1994). Generally, these Ca-enrichment-induced alterations have a net beneficial effect, enabling the plant root system to explore a greater proportion of the soil profile, in a shorter period of time, to a deeper depth, thereby extracting more of the essential elements required to sustain optimal growth rates.

To predict the response of a wheat crop root system to global change, more specific root studies characterizing root growth and morphology under elevated Ca are required. The objective of this investigation was to characterize and quantify root length density, surface area, and root tissue density, and relate any alterations in these parameters with the growth and development of a monoculture wheat crop grown in Ca-ambient compared with Ca-enriched and well-watered compared with water-stressed soil moisture regimes.

APPROACH: A two-year field study on hard red spring wheat (*Triticum aestivum* L. cv. Yecora Rojo) was conducted in an open field at the University of Arizona, Maricopa Agricultural Research Center, located 50 km south of Phoenix, Arizona (33.1 °N, 112.0 °W). Wheat seeds were sown into flat beds at 0.25-m row spacings. During the 1992-3 season, planting occurred on December 15, 1992 at a plant population of 130 plants m^{-2}, 50% emergence occurred on January 1, 1993, and the crop was harvested May 25-27, 1993. During the 1993-4 season, wheat was sown at a plant population of 180 plants m^{-2} on December 7-8, 1993; 50% emergence occurred on December 28, 1993, and the crop was harvested on June 1, 1994. Following sowing, a FACE apparatus (Hendrey, 1993) was erected on site to enrich the Ca of ambient air (~350 μmol mol^{-1}) to a 550 μmol mol^{1} treatment level. A sub-surface drip tape irrigation system supplied a full irrigation (100% evaporative demand) and a 50% reduction in water supply (split-strip-plot) treatment. A preplant application of nitrogen along with several chemigation applications provided a total of 277 and 261 kg N ha^{-1}, and 44 and 29 kg P ha^{-1} for the two years, respectively.

Root core samples were taken when the crop reached the three-leaf, tillering, stem-elongation, anthesis, dough-development, and final harvest stages of growth, which corresponded to days of year (DOY) 16, 36, 63, 92, 113, and 159, respectively in 1993 and DOY 3, 26, 40, 102, 118, and 154, respectively in 1994. Two in-row and one inter-row root cores (86 mm ID) were collected on each sampling date (four replications at three-leaf and tillering, three replicates at stem-elongation, anthesis and dough-development and two replicates at final harvest) using a gas-driven soil core device. Extracted cores were divided into individual core sections from the top of the soil profile downward as follows: three-leaf stage cores were taken to a total depth of 0.30-m and divided into three core lengths of 0.05, 0.10 and 0.15-m; tillering stage cores were taken to a depth of 0.60-m and divided into lengths of 0.05, 0.10, 0.15, 0.15, and 0.15-m; stem-elongation, anthesis, dough-development and final harvest stage cores were sampled to a 1.0-m depth and divided into lengths of 0.15, 0.15, 0.15, 0.15, 0.20 and 0.20-m. Root and organic debris material in each core section were elutriated from the soil with a hydropneumatic elutriation system. Root length and surface area for the entire core volume were calculated with software provided with the imaging device. Root density was determined by dividing the dry weight by the length. All root parameters were normalized for the volume of the individual core sections and the midpoint of the core was determined for graphic display.

FINDINGS: Seasonal trends in individual treatment (CO_2 Irr) means pooled across core position for root length density, and density are illustrated in figure 1 and figure 2, respectively. Although not illustrated, root surface area results were comparable to those of root length density as expected. The ratios of main CO_2 (FACE to Control), Irr (Wet to Dry) and P (in-row to inter-row) effect means were derived for all growth stages and soil depths for both seasons. The percentages of times (sixty-four comparisons) that these ratios were greater than unity was determined for root length density, surface area, and density, respectively. CO_2 effect means were greater than unity 86%, 83% and 39% of the times indicating that elevated CO_2 stimulated root length density and surface area for most instances, but had minimal effect or tended to decrease density; Irr effect means where greater than unity 38%, 14% and 25% of the times indicating that water-stress increased root length density and surface area, and it also resulted in the roots being more dense in most cases; P effect means were 67%, 63% and 52% which simply means there were more roots in the rows than between.

INTERPRETATION: The fibrous root system of a wheat crop growing in a future CO_2 -enriched world will have higher root length density resulting in increased surface area, but root density will remain unaltered. Any increase in root biomass, therefore will be due to an increase in the total root length, rather than an increase in root width. A more extensive root system within a soil depth will have an additive effect across the soil profile, thereby enhancing exploration of the soil volume to a greater depth in a shorter period of time. Such an increase should enhance the plants' capacity to mine soil moisture and nutrients more efficiently, particularly where deficits could reduce growth. This CO_2-based enhancement might result in an enhanced rate of survival for C3 cool season grasses in more marginal areas and quite possibly expand their ranges into presently less favorable regions of their biome.

FUTURE PLANS: A FACE experiment has been completed during 1995-6 and another is scheduled for the 1996-7 season. One objective of these experiments is to expand out understanding of root system dynamics, particularly under CO_2 -enriched and nitrogen limited environments.

COOPERATORS: Operational support was contributed by the Potsdam Institute for Climate Impact Research, Potsdam, Germany and by the Carbon Dioxide Research Program of the Office of Health and Environmental Research of the Department of Energy. We also acknowledge the helpful cooperation of Dr. Roy Rauschkolb and his staff at the University of Arizona, Maricopa Agricultural Center. The FACE apparatus was furnished by Brookhaven National Laboratory, and we are grateful to Mr. Keith Lewin, Dr. John Nagy, and Dr. George Hendrey for assisting in its installation and consulting about its use. This work contributes to the Global Change Terrestrial Ecosystem (GCTE) Core Research Programme, which is part of the International Geosphere-Biosphere Programme (IGBP).

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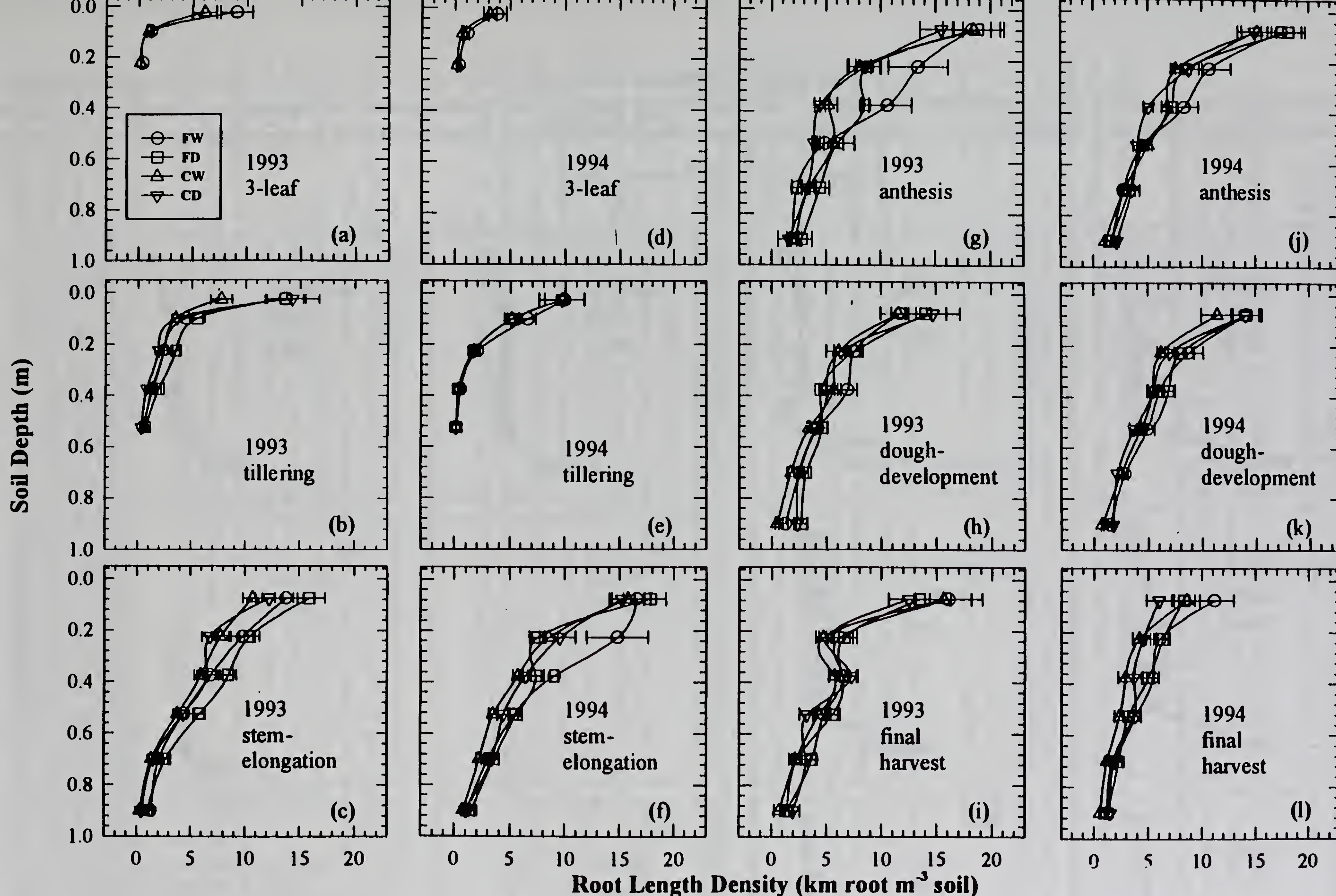

Figure 1. Mean root length density (weighted mean of two in-row and one inter-row root cores) vs. midpoint depth of soil core section for a spring wheat (*Triticum aestivum* L. cv Yecora Rojo) crop for six growth stages during 1993 and 1994, respectively. Treatment means are for FACE Wet (FW), FACE Dry (FD), CONTROL Wet (CW), and CONTROL Dry (CD). Error bars are one standard error of the mean.

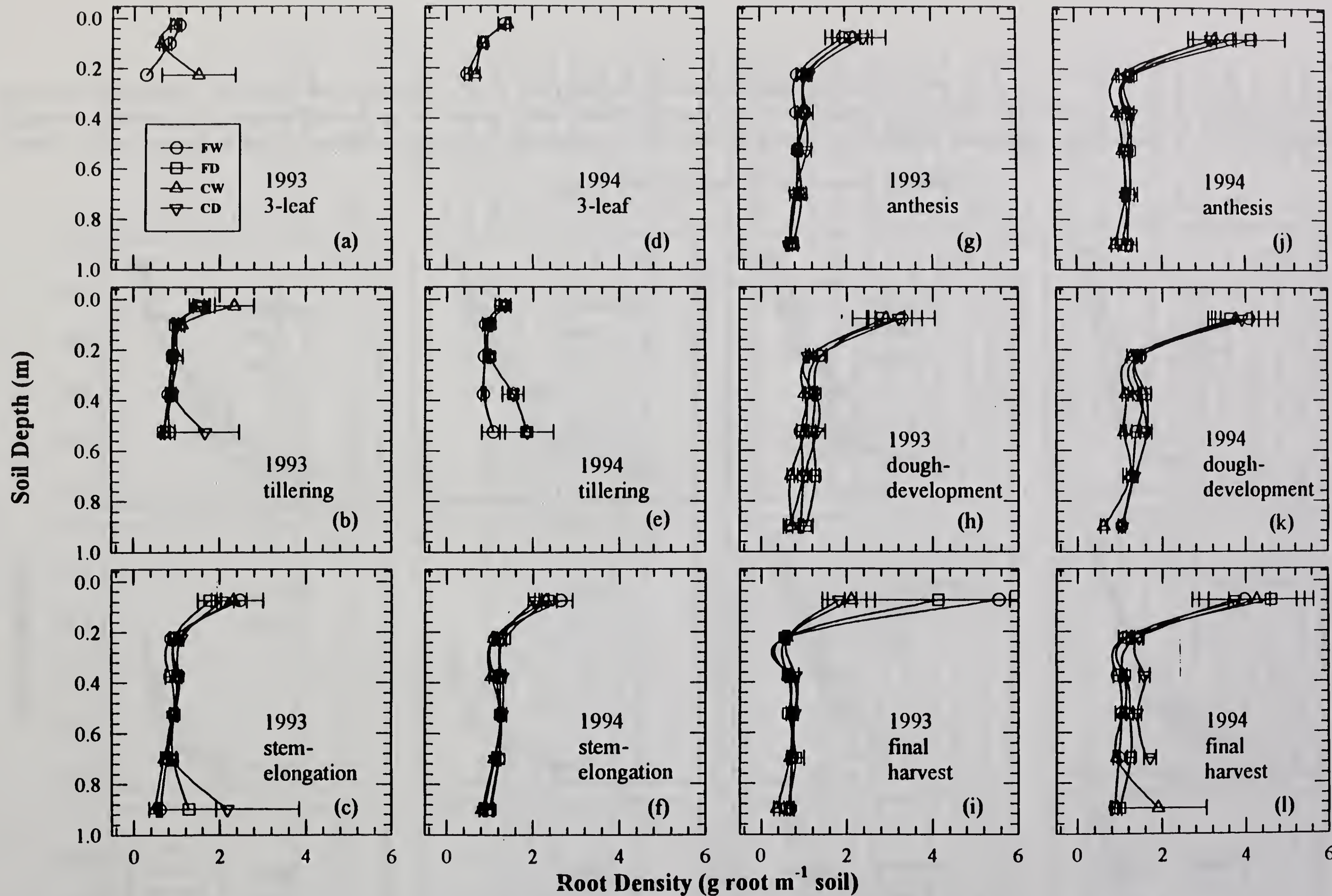

Figure 2. Mean root density (weighted mean of two in-row and one inter-row root cores) vs. midpoint depth of soil core section for a spring wheat *(Triticum aestivum* L. cv Yecora Rojo) crop for six growth stages during 1993 and 1994, respectively. Treatment means are for FACE Wet (FW), FACE Dry (FD), CONTROL Wet (CW), and CONTROL Dry (CD). Error bars are one standard error of the mean.

EFFECTS OF FREE-AIR CO_2 ENRICHMENT (FACE) AND SOIL NITROGEN ON THE ENERGY BALANCE AND EVAPOTRANSPIRATION OF WHEAT

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PROBLEM: The CO_2 concentration of the atmosphere is increasing and expected to double sometime during the next century. Climate modelers have predicted that the increase in CO_2 will cause the earth to warm and precipitation patterns to be altered. Such increases in CO_2 and possible climate change could affect the hydrologic cycle and future water resources. One component of the hydrologic cycle that could be affected is evapotranspiration (*ET*), which could be altered because of the direct effects of CO_2 on stomatal conductance and on plant growth. Therefore, one important objective of the Free-Air CO_2 Enrichment (FACE) Project (See Kimball et al., this volume) is to evaluate the effects of elevated CO_2 on the ***ET*** of wheat.

APPROACH: Briefly, the FACE experiments were conducted as follows: Four toroidal plenum rings of 25 m diameter constructed from 12" irrigation pipe were placed in a wheat field at Maricopa, Arizona, shortly after planting. The rings had 2.5-m-high vertical pipes with individual valves spaced every 2 m around the periphery. Air enriched with CO_2 was blown into the rings, and it exited through holes at various elevations in the vertical pipes. Wind direction, wind speed, and CO_2 concentration were measured at the center of each ring. A computer control system used wind direction information to turn on only those vertical pipes upwind of the plots, so that the CO_2-enriched air flowed across the plots, no matter which way the wind blew. The system used the wind speed and CO_2 concentration information to adjust the CO_2 flow rates to maintain CO_2 concentrations at 200 ppm by volume CO_2 above ambient (about 360 ppm in daytime) at the centers of the rings. Four matching Blower rings with similar air flow but no added CO_2 were also installed the field.

In addition to the CO_2 treatments, varying soil nitrogen was also a factor in the this experiment. Using a split-plot design, the main circular CO_2 plots were divided into semi-circular halves, with each half receiving either 350 (High N) or 70 (Low N) kg N/ha of NH_4NO_3 fertilizer through the drip irrigation system.

The determination of the effects of elevated CO_2 on ***ET*** by traditional chambers is fraught with uncertainty because the chamber walls that constrain the CO_2 also affect the wind flow and the exchange of water vapor. Therefore, a residual energy balance approach was adopted, whereby ***ET*** was calculated as the difference between net radiation, R_n, soil surface heat flux, G_0, and sensible heat flux, H:

$$\lambda ET = R_n - G_0 - H$$

R_n was measured with net radiometers, and G_0 with soil heat flux plates. H was determined by measuring the temperature difference between the crop surface and the air and dividing the temperature difference by an aerodynamic resistance calculated from a measurement of wind speed. Air temperatures were measured with aspirated psychrometers, and crop surface temperatures were measured with infrared thermometers (IRTs) mounted above each plot. Net radiometers, IRTs, psychrometers, cup anemometers, soil heat flux plates, and soil thermocouples were deployed in plots of all four treatments in Replicate 3, and net radiometers and IRTs were also deployed in Replicate 4. Fifteen-minute averages were recorded on a datalogging system. The net radiometers and IRTs were switched weekly between the FACE and Blower plots.

FINDINGS: The elevated CO_2 concentration in the FACE plots increased foliage temperatures by 0.6 and 1.1 °C at high and low N, respectively, during the daytime for much of the growing season (fig. 1). As illustrated in figure 2b for March 27, 1996, soil heat flux was generally very small. Net radiation was the largest component of the energy balance (fig. 2a), and sensible heat flux was moderate (fig. 2c), so latent heat flux, λET, tended to follow net radiation (fig. 2d). However, associated with the increases in foliage temperatures, there were small

but consistent increases in sensible heat flux. Summing daily totals of latent heat flux and plotting FACE values against the corresponding Blower values, it can be seen that FACE reduced λET by about 6% at high N (fig. 3) and 16% at low N (fig. 4). Moreover, the regression line at high N is very close to those from 1992-3 and 1993-4 (fig. 3), which gives greater credence to the conclusion that enrichment to about 550 ppmv CO_2 reduces λET by about 6% at ample water and N.

INTERPRETATION: It appears from these data that irrigation requirements for wheat may be somewhat lower in the future high-CO_2 world (provided that any global warming is small).

FUTURE PLANS: The data from the 1995-6 experiment will be analyzed, and the results will be reported. A replicate FACE Wheat experiment will commence in December 1996 to evaluate the response of wheat to FACE when soil nitrogen is limited. Micrometeorological parameters required to characterize the growing conditions in support of modeling efforts will be measured.

COOPERATORS: See report, "Progress and Plans for the Free-Air CO_2 Enrichment (FACE) Project," in this volume.

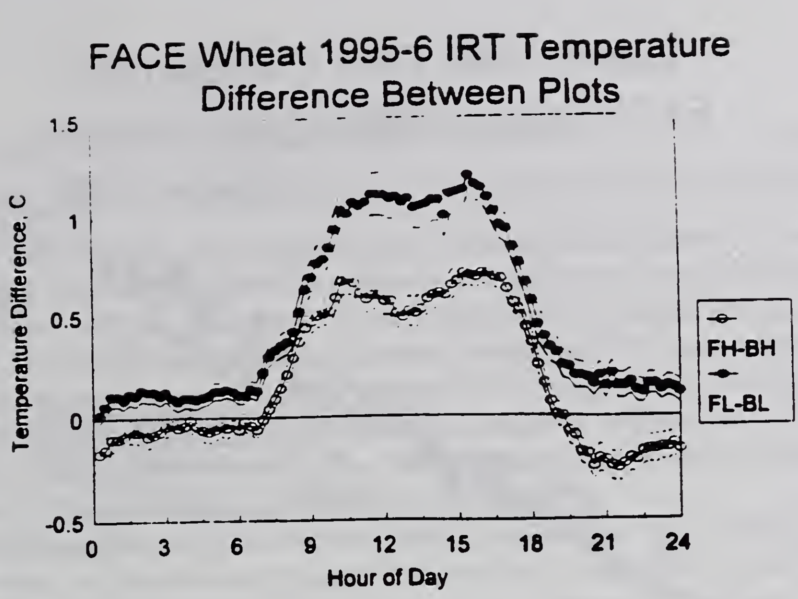

Figure 1. Near-season-long average foliage temperature differences between the FACE-High N (FH) and the Blower-High N (BH) plots and between the FACE-Low N (FL) and the Blower-Low N (BL) plots versus time of day. The data are the mean differences for each particular 15-min period averaged over 73 days for which good data were available between February 6 and May 7 for the High N and for 65 days between February 6 and April 27 for Low N. This selection of data excluded early season data when the instruments viewed soil, and late season data when the crop senesced.

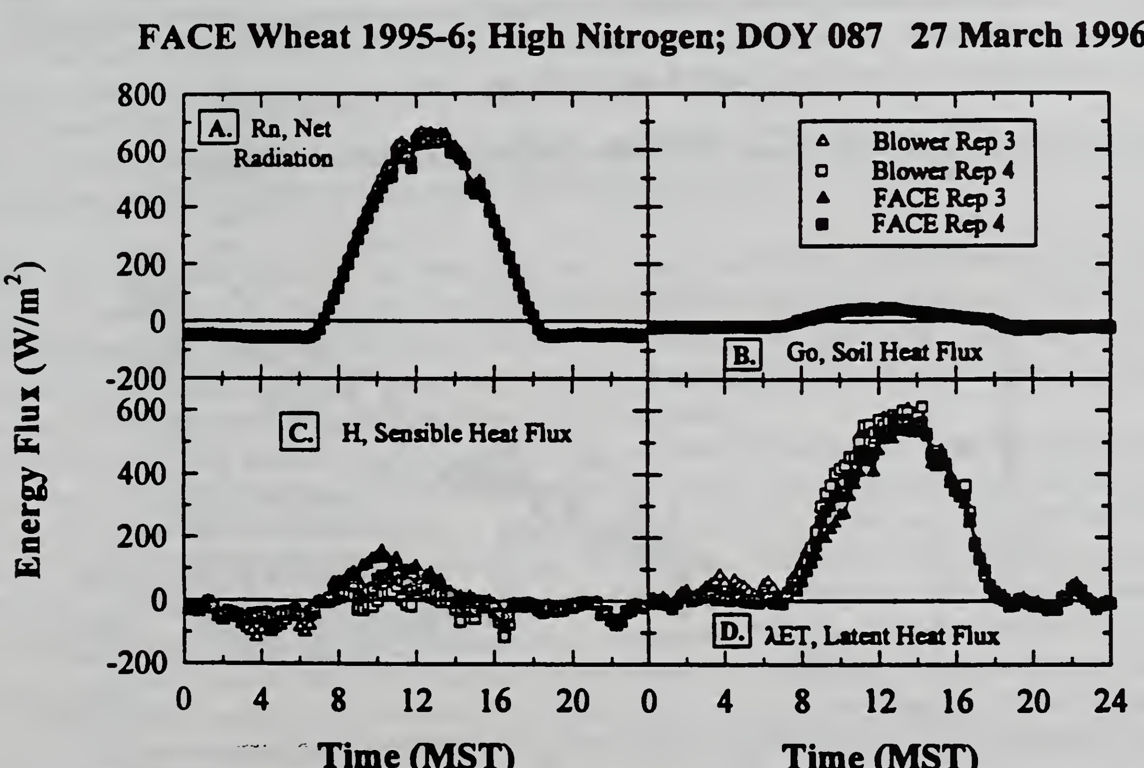

Figure 2. Net radiation, R_n (A), soil heat flux, G_o (B), sensible heat flux, H (C), and latent heat flux, λET (D) in Blower and FACE plots versus time of day on 27 March 1996 in the High nitrogen plots. In the legends, B and F indicate the Blower and FACE CO_2 treatments; H and L indicate High and Low soil nitrogen; and 3 and 4 indicate replicate numbers.

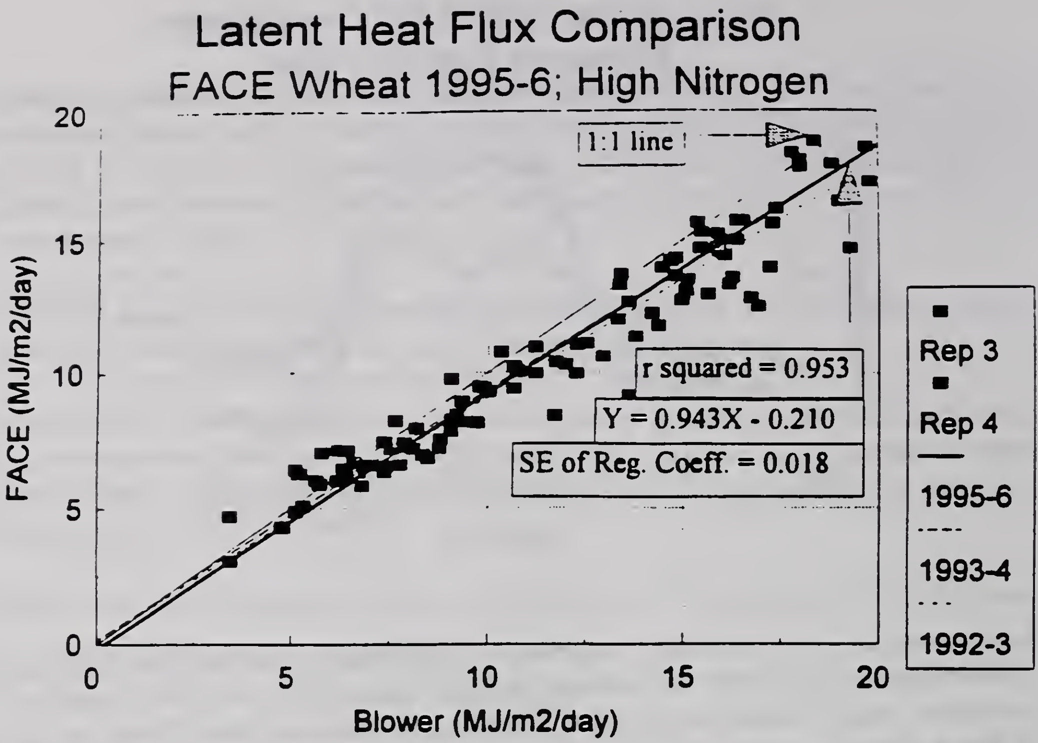

Figure 3. Daily total FACE latent heat flux, λET, versus the corresponding Blower λET for 73 days between February 6 and May 7 for the High nitrogen plots. This selection of data excluded early season data when the instruments viewed soil and late season data when the crop senesced. Also shown are the regression lines for these data and for similar data sets obtained in 1992-3 and 1993-4.

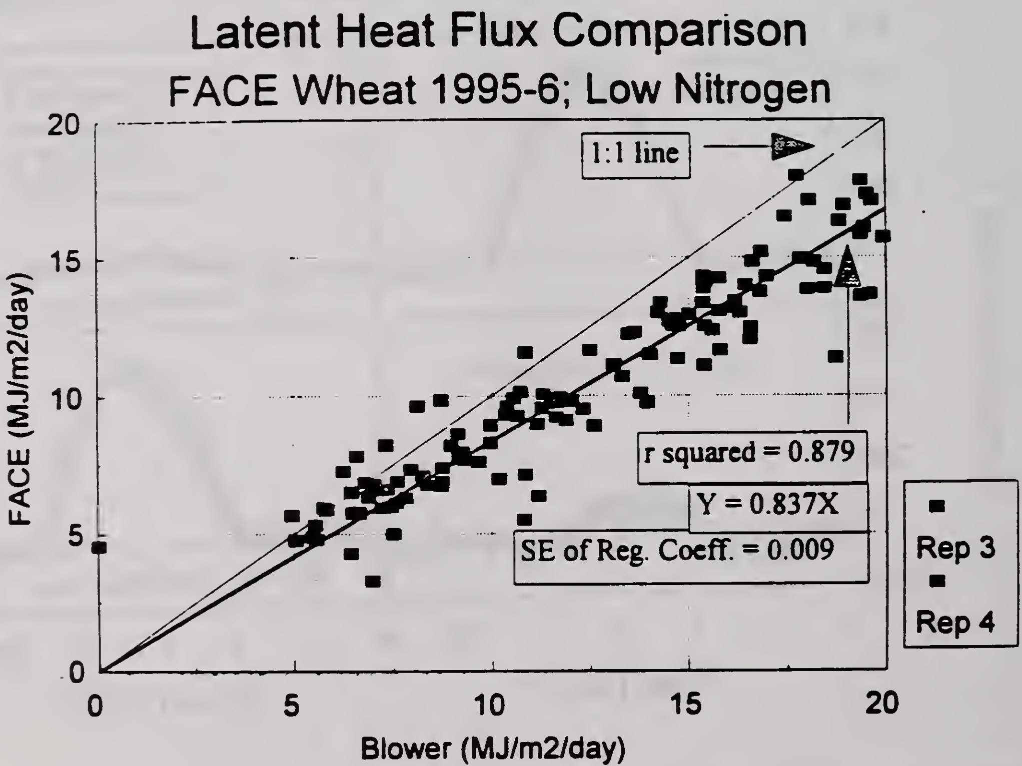

Figure 4. Daily total FACE latent heat flux, λET, versus the corresponding Blower λET for 65 days between February 6 and April 27 for the Low nitrogen plots. This selection of data excluded early season data when the instruments viewed soil, and late season data when the crop senesced.

CO_2 ENRICHMENT OF TREES

S. B. Idso, Research Physicist; and B. A. Kimball, Supervisory Soil Scientist

PROBLEM: The continuing rise in the CO_2 content of Earth`s atmosphere is believed by many people to be the most significant ecological problem ever faced by humanity because of the widespread assumption that it will lead to catastrophic global warming via intensification of the planet's natural greenhouse effect. Largely unknown, however, are the many beneficial effects of elevated atmospheric CO_2 concentrations on Earth's plant life. Hence, it is imperative that this other aspect of atmospheric CO_2 enrichment be elucidated so that the public can have access to the full spectrum of information about the environmental consequences of higher-than-ambient levels of atmospheric CO_2. Only under such conditions of complete and wide-ranging understanding can the best decisions be made relative to national and international energy policies.

As forests account for two-thirds of global photosynthesis, and are thus the primary players in the global biological cycling of carbon, we have chosen to concentrate on trees within this context. Specifically, we seek to determine the direct effects of atmospheric CO_2 enrichment on all aspects of their growth and development; and we hope to be able to determine the ramifications of these direct effects for global carbon sequestering, which may also be of considerable significance to the climatic impact of atmospheric CO_2 enrichment, as the biological sequestering of carbon is a major factor in determining the CO_2 concentration of the atmosphere and the ultimate level to which it may rise.

APPROACH: In July 1987, eight 30-cm-tall sour orange tree (*Citrus aurantium* L.) seedlings were planted directly into the ground at Phoenix, Arizona. Four identically-vented, open-top, clear-plastic wall chambers were then constructed around the young trees, which were grouped in pairs. CO_2 enrichment--to 300 ppmv (parts per million by volume) above ambient--was begun in November 1987 to two of these chambers and has continued unabated since that time. Except for this differential CO_2 enrichment of the chamber air, all of the trees have been treated identically, being irrigated at periods deemed appropriate for normal growth and fertilized as per standard procedure for young citrus trees.

Numerous measurements of a number of plant parameters have been made on the trees, some weekly, some monthly, and some annually. Results of our findings are summarized below.

FINDINGS: (1) Over the course of our long-term sour orange tree study, we have measured the trunk circumference of each tree at the mid-point of each month; and from the end of the third year of the study, we have counted the number of oranges removed from each tree at the conclusion of each year's harvest. At the end of year 7, we also measured the diameter of every orange removed from each tree, along with the rind thicknesses of 240 randomly selected oranges from each of the two CO_2 treatments.

From these data and other studies reported in prior years, we have developed an eight-year history of the growth-promoting effects of atmospheric CO_2 enrichment on sour orange trees. Figure 1, for example, depicts the yearly production of new tree " biovolume," which we have defined to be the sum of the new trunk and branch volume produced each year plus each year's volume of fruit rinds. Plots such as these typically rise very slowly in the early years of tree growth, pass through a rapidly increasing juvenile phase, and ultimately level off at some relatively constant equilibrium value characteristic of maturity. Consequently, at the end of year 7, we thought that the trees were close to achieving their long-term maximum growth rates, as the two growth curves of figure 1 looked as if they were beginning to level off. The data from year 8, however, suggest that we may still have a way to go before we can determine the ultimate long-term effects of atmospheric CO_2 enrichment on these trees, which is, of course, our primary goal.

To this point in time, however, the data of figure 1 suggest that the CO_2-enriched tees will likely always produce more biomass each year than will the ambient treatment trees. This assumption is strengthened by the cumulative biovolume production histories of figure 2, where it can be seen that in terms of the absolute magnitudes of their biovolume production, the trees are becoming increasingly different from each other with each passing year.

Another perspective on this topic is provided by the data of figure 3, where we have plotted the CO_2-enriched/ambient-treatment ratios of the lengths of time required for the biovolumes of the trees of each treatment to reach specified sizes. This plot reveals that throughout almost the entire history of the experiment, the CO_2-enriched trees have achieved specified cumulative biovolume values in about 77% of the time required for the ambient-treatment trees to do so. Conversely, it takes the ambient-treatment trees fully 30% more time to achieve a given size than it does the CO_2-enriched trees. At the eight-year point of the study, for example, the ambient-treatment trees were approximately 2 years behind the CO_2-enriched trees in terms of their total cumulative productivity.

(2) At weekly intervals throughout years 4 through 7 of the sour orange tree study, we measured chlorophyll a contents of 60 leaves on each of the eight trees with a hand-held chlorophyll meter that was specifically calibrated for the trees of our study. At bi-monthly intervals we also measured the areas, dry weights, and nitrogen contents of 68 leaves from each tree. Expressed on a per-unit-leaf-area basis, and averaged over the four-year period, leaves from the four CO_2-enriched trees contained 4.8% less chlorophyll and nitrogen than leaves from the four ambient-treatment trees. However, based on an empirical relationship we had previously developed between trunk cross-sectional area and the number of leaves on a tree, along with the results of a previously published study of CO_2 effects on leaf size, we calculated that the total chlorophyll a and nitrogen contained in all the leaves of the CO_2-enriched trees averaged 75% more than the total chlorophyll a and nitrogen contained in all the leaves of the ambient-treatment trees over the four-year course of the study. It is interesting to note that this percentage enhancement is identical to the percentage increase in atmospheric CO_2 concentration experienced by the CO_2-enriched trees. With only two CO_2 treatments, however, we cannot say whether this exact correspondence is anything more than coincidence.

INTERPRETATION: The implications of our findings have a direct bearing on the current debate over anthropogenic CO_2 emissions. They demonstrate that CO_2 is an effective aerial fertilizer, significantly enhancing the growth of sour orange trees, as well as their ability to remove CO_2 from the atmosphere.

FUTURE PLANS: We hope to continue the sour orange tree experiment for three to four more years, or as long as is needed for them to achieve their ultimate equilibrium growth rates.

COOPERATORS: U.S. Department of Energy, Atmospheric and Climate Research Division, Office of Health and Environmental Research.

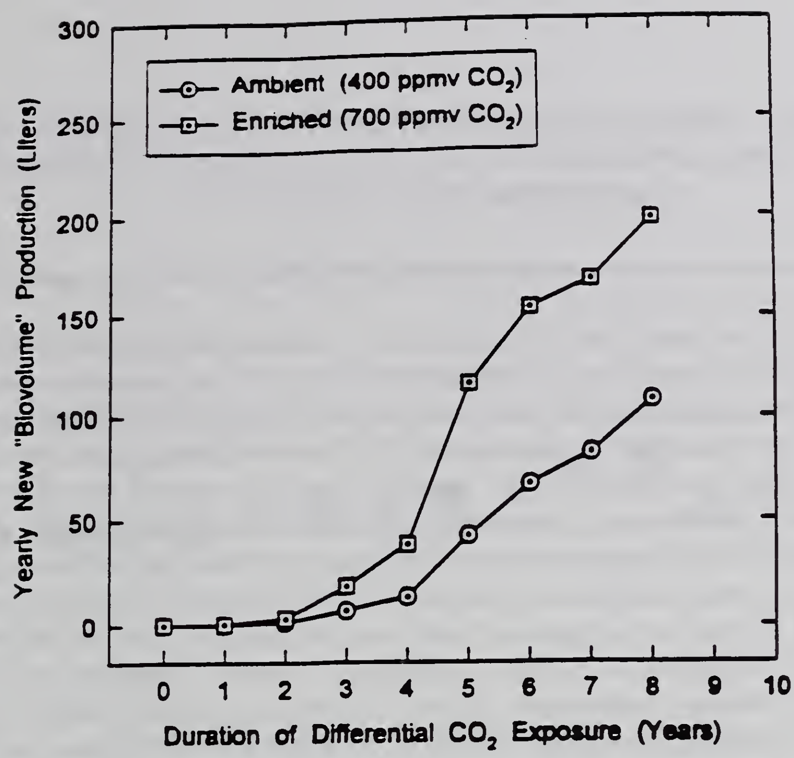

Figure 1. The complete eight-year time courses of the mean yearly biovolume production of the ambient and CO_2-enriched trees.

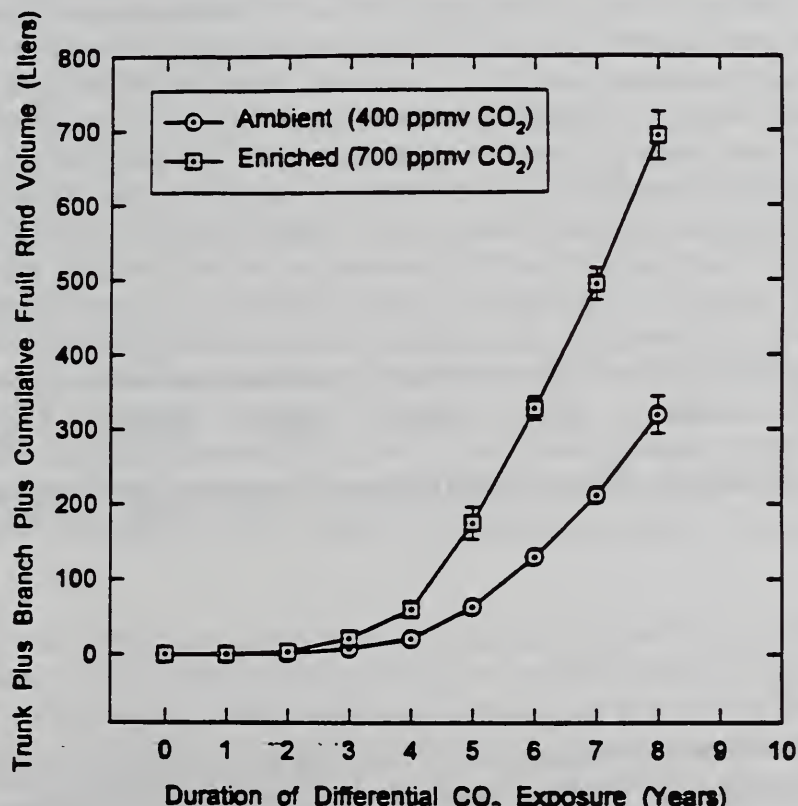

Figure 2. The complete eight-year time courses of the mean trunk plus branch plus cumulative fruit rind volumes produced per tree (with their associated standard errors) in each of the two atmospheric CO_2 treatments.

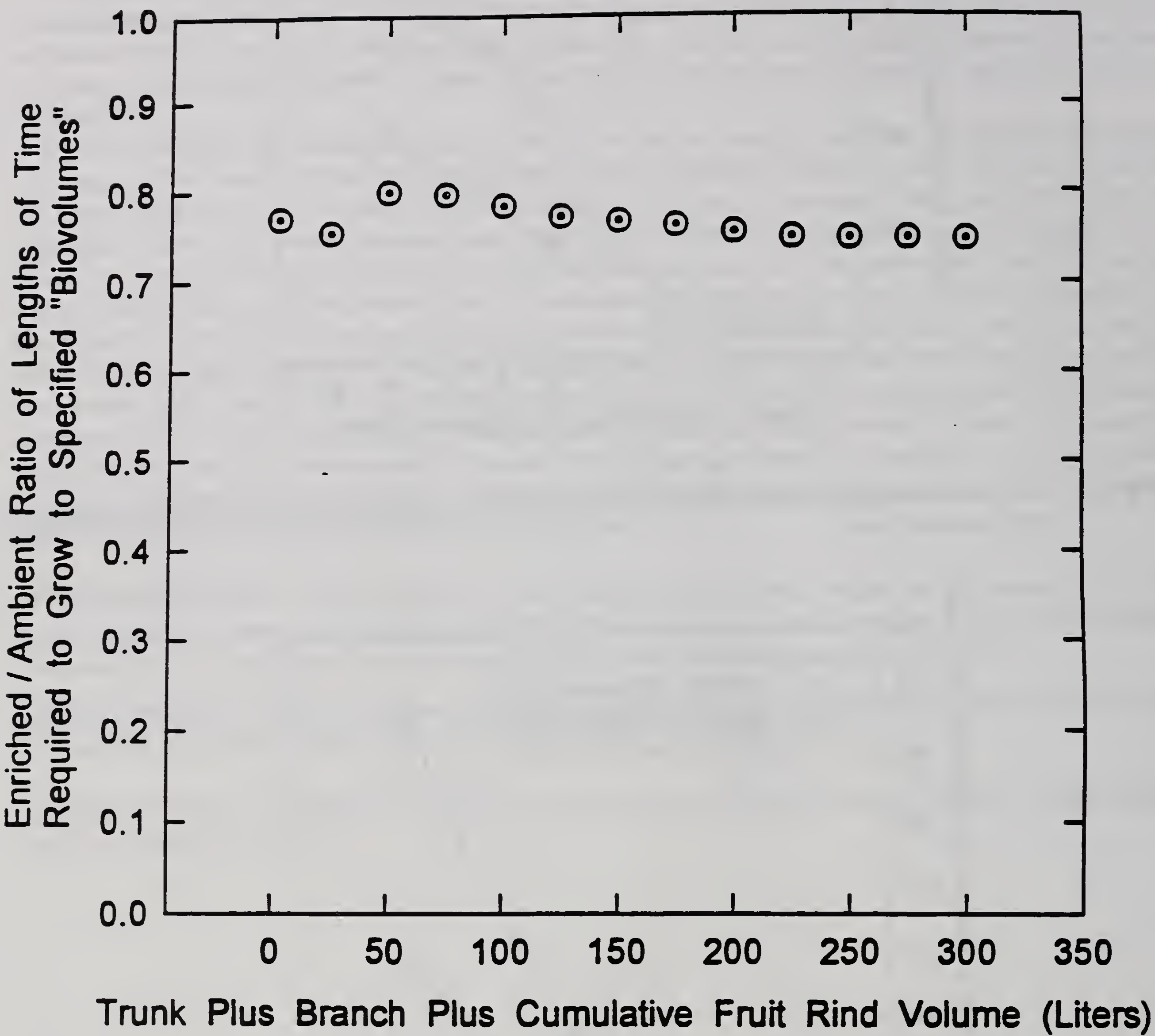

Figure 3. The CO_2-enriched/ambient-treatment ratios of the lengths of time required for the mean trunk plus branch plus cumulative fruit rind volumes of the trees of the two CO_2 treatments to reach identical values.

SIMPLE TECHNIQUES FOR CONDUCTING CO_2 ENRICHMENT AND DEPLETION EXPERIMENTS ON AQUATIC AND TERRESTRIAL PLANTS: THE "POOR MAN'S BIOSPHERE"

S. B. Idso, Research Physicist

PROBLEM: In order to act in the best interests of the biosphere in the face of the rising CO_2 content of earth's atmosphere, we need to determine the effects of atmospheric CO_2 enrichment on the growth habits of as many different plants as possible, both singly and in combination with competing plants and animals. Also needed is a knowledge of how the ongoing rise in the air's CO_2 content may interact with other environmental changes--such as global warming, more frequent and intense drought, and intensified soil, water, and air pollution--so we can determine if the deleterious effects of these latter phenomena on agricultural productivity and the viability of natural ecosystems will be moderated or exacerbated by the concurrent rise in atmospheric CO_2.

So many questions, so little time--this is the problem we face with respect to what the nations of the earth have formally recognized as the most pressing environmental challenge of our day, an issue that requires such a massive research effort to adequately address that it is almost beyond our capacity to successfully respond in the required time frame. Consequently, in an attempt to expand our research capabilities in this important area of science, this project has as its goal the development of a suite of simple and inexpensive experimental techniques that will enable a host of new investigators to conduct significant research on a variety of questions related to the role of atmospheric CO_2 variability in ongoing and predicted global environmental change.

APPROACH: Over the first three years of the project, a set of guidelines has been developed for using inexpensive and readily available materials to construct experimental growth chambers--"poor man's biospheres" --wherein CO_2 enrichment and depletion studies of both aquatic and terrestrial plants may be conducted. In their most basic form, these enclosures consist of no more than simple aquariums covered by thin sheets of clear polyethylene that are taped to their upper edges to isolate their internal air spaces from the room or outside air. A number of low-cost, low-technology ways of creating a wide range of atmospheric CO_2 concentrations within these enclosures has also been developed. Several of the CO_2 enrichment techniques utilize the CO_2 that is continuously evolved by the oxidation of organic matter found in common commercial potting soils, while others rely on the CO_2 that is exhaled by the experimenter. When CO_2 depletion is desired, the growth of the experimental plants themselves can be relied upon to lower the CO_2 contents of the biospheres' internal atmospheres, as can the photosynthetic activity of ancillary algal populations that often occur in watery habitats and that can be induced to grow in terrestrial environments as well. For all of these different situations, a set of simple procedures for measuring biospheric CO_2 concentrations has additionally been developed. These techniques utilize an inexpensive colormetric CO_2 test kit that is sold in tropical fish stores throughout the world and is thus also readily available to practically anyone. Finally, to illustrate the usefulness of this methodology, numerous experiments were conducted on a common terrestrial plant and a fully submerged and a floating aquatic species.

FINDINGS: (1) Figure 1 depicts the growth response of the common Devil's Ivy or Golden Pathos (*Scindapsus aureus*) plant to atmospheric CO_2 enrichment (to 2156 ppmv) and depletion (to 68 ppmv) that I have derived by these simple means. The solid line I have fit to the data is a rectangular hyperbola of the form $Y=[a(X-b)c]/[a(X-b)+c]$, where a is the initial slope of the function, b is the CO_2 concentration (X) at which growth is zero, and c is the asymptotic value of the normalized growth rate (Y), which has been set equal to unity at 365 ppmv -- the current mean value of the earth's atmospheric CO_2 concentration. For this common house plant, which was grown under favorable conditions of light, water, and nutrients, a $=0.00583$ $(ppmv)^{-1}$, b=61.3 ppmv, and c=2.29. These results suggest that a 50% reduction in the current atmospheric CO_2 concentration to 182 ppmv -- a value typical of earth's atmosphere at the peak of the last ice age 15 to 20 thousand years ago -- would likely reduce the growth rates of Golden Pathos plants to only a little over half (54%) of what they are today. Looking to the

future, they suggest that a doubling of the current atmospheric CO_2 concentration to 730 ppmv would likely boost their growth rates by approximately 44%.

(2) Figure 2 depicts the increase in the growth of a submerged aquatic macrophyte--Corkscrew Vallisneria (*Vallisneria tortifolia*)--when the CO_2 content of the air above the surface of the water within which it is growing is doubled at a variety of different water temperatures. This increasing growth response with increasing temperature is characteristic of many plants--both aquatic and terrestrial--and it ultimately rises to infinity at the temperature where plants grown at the ambient CO_2 concentration succumb to heat stress and die. An example of the protection against thermal death that is provided to plants by elevated levels of atmospheric CO_2 (and which results in the steep increase in relative growth rate experienced by plants exposed to high CO_2 concentrations at high temperatures) is portrayed for this particular species in Figure 3.

INTERPRETATION: The excellent results obtained to date, which compare well with what we already know about the growth responses of plants to atmospheric CO_2 enrichment and depletion, suggest that the simple methodology developed over the past three years, combined with the inexpensive "poor man's biosphere," represent a valid approach to investigating the effects of atmospheric CO_2 variability on both aquatic and terrestrial plants within the context of ongoing and predicted global environmental change. This methodology should thus provide a low-cost, low-technology opportunity for people who previously may have lacked the funds and equipment to address such questions to now go on to tackle even more complex problems with but a modest investment in equipment and supplies. These new research procedures should also play a major role in expanding instructional opportunities for students of biology at all levels of education in our public and private schools.

FUTURE PLANS: Over the next two years, I plan to further refine some of the techniques I have developed; and I plan to actually use them in several high-school and middle-school science classes in cooperation with local teachers. This real-world experience will enable me to determine the best ways to introduce the concepts I have developed into educational curriculums and actually get them implemented, hopefully inspiring more of the rising generation to seek careers in science.

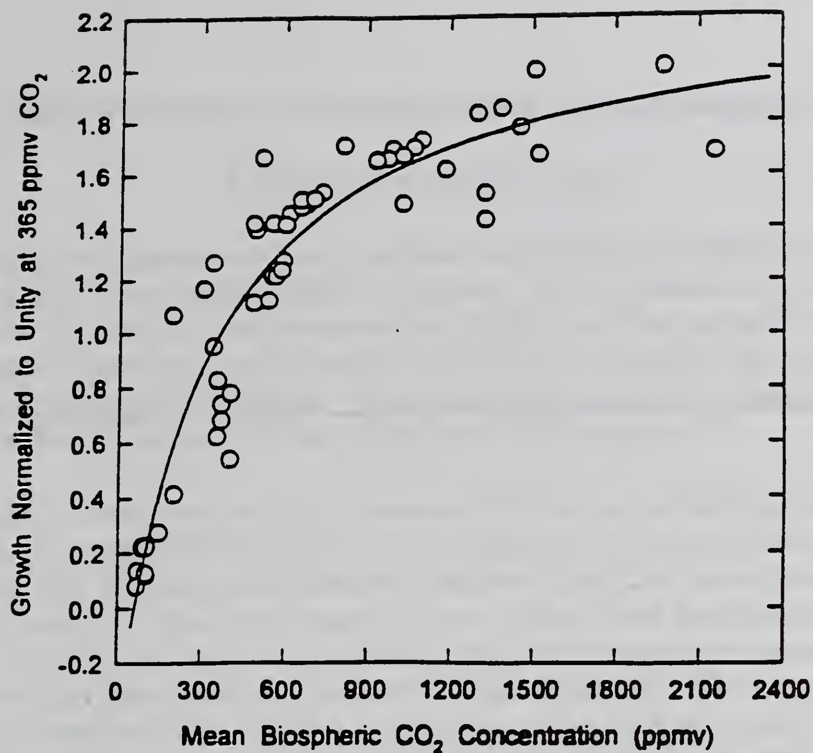

Figure 1. Dry matter production rates of Golden Pathos plants normalized to a dimensionless value of unity at 365 ppmv CO_2 vs. mean biospheric CO_2 concentration, as derived from a large number of indoor and outdoor experiments in "poor man's biospheres."

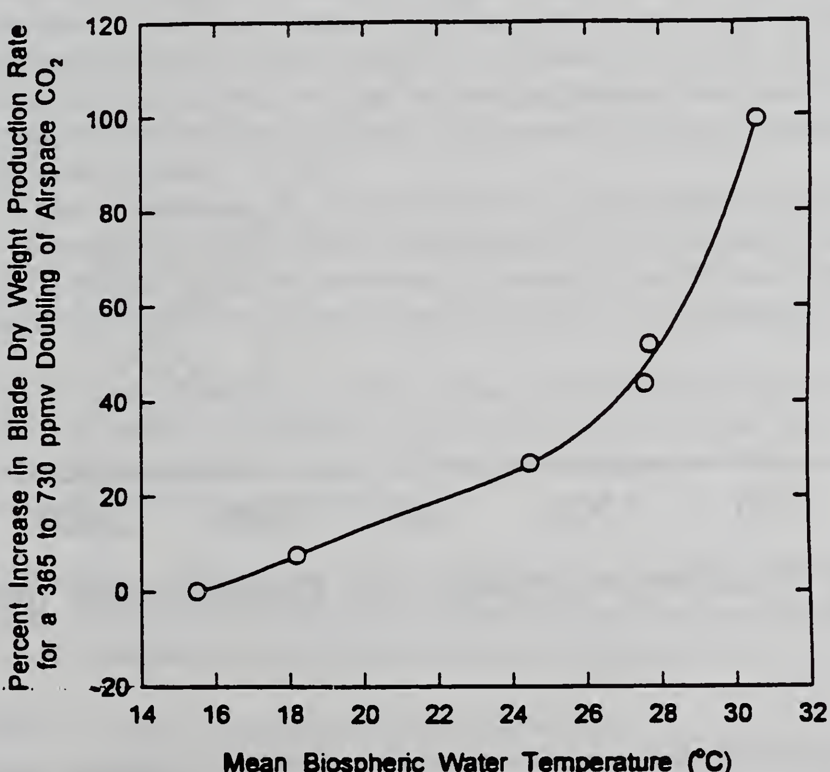

Figure 2. Percentage increases in blade biomass production of Corkscrew Vallisneria plants caused by a 365 to 730 ppmv doubling of the CO_2 concentration of the air above the water within which the plants were totally submerged and with which the entrapped air of their respective biospheres was in equilibrium vs. mean biospheric water temperature.

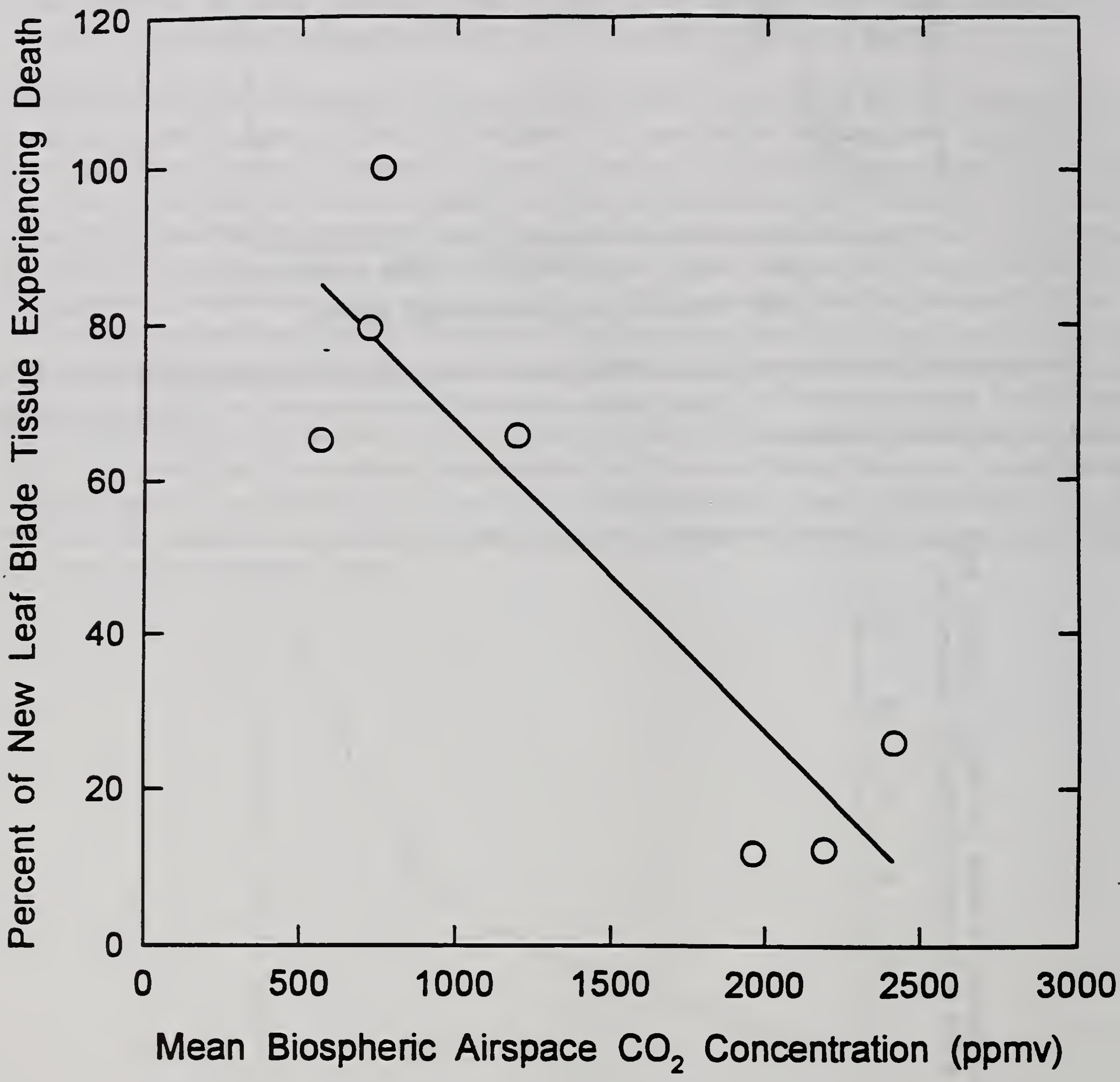

Figure 3. Percentages of newly-produced leaf blade tissue of Corkscrew Vallisneria plants that had died at a specific point in time as a result of the gradually rising water temperature of this experiment plotted as functions of their mean biospheric airspace CO_2 concentrations to the same point in time.

SOIL CO_2 FLUX IN WHEAT: NITROGEN AND CO_2 ENRICHMENT EFFECTS

F. S. Nakayama, Research Chemist

PROBLEM: Numerous investigations are being conducted to determine the effects of increased atmospheric CO_2 concentration on crop production and global CO_2 balance. The soil system can be affected by changes in environmental CO_2 levels. It can act as both a source and sink for CO_2, and thus, its impact on the overall carbon balance of the environment is not as simple as it appears. Soil CO_2 flux is an important component for modeling plant growth and the sequestering of C in the soil. The objective of this study is to determine the soil CO_2 flux in wheat as it is affected by soil nitrogen (N) and atmospheric CO_2 enrichment.

APPROACH: The soil CO_2 fluxes were determined in a wheat field as part of the field free-air CO_2 enrichment experiment (FACE) conducted at the University of Arizona Maricopa Agricultural Center, Maricopa, Arizona. The flux measurements were based on procedures previously developed. A detailed description of the FACE operation is presented elsewhere in this 1996 "Annual Research Report" that describes the overall free-air CO_2 enrichment (FACE) experiment on wheat. The flux measurements were made throughout the wheat culture in the CO_2 enriched (200 ppm above ambient) and low (70 kg/ha) and high (350 kg/ha) N treatments. The treatment combination consisted of four check (or blower) and four FACE plots with low and high N levels superimposed in a strip-split plot design. Four flux sampling chambers were used for each CO_2 level x N combination with four replicates per treatment for a total of 64 flux sampling sites.

FINDING: The soil CO_2 flux values for 1995-1996 were similar to those for the 1993-1994 wheat experiment at the same site, where water level was the variable instead of N. The fluxes for the different treatment combinations are illustrated in figure 1. The FACE-High N fluxes were consistently higher than the other treatments, whereas the Blower-Low N were consistently lower. The treatment effects, particularly for the low- and high-N level, were readily observable (Blower-High N vs. Blower-Low N). The flux differences were more evident during the period (days 78 to 134) when the microbial and plant activities were the highest. The fluxes were essentially the same for the last plotted 144-day, which occurred after the CO_2 system was turned off and the wheat was in a fully mature state.

For the 9 of the 11 measurement days, significant differences were present for the N and CO_2 enrichment treatments (table 1). On average, the FACE treatment increased soil CO_2 flux by 6 and 27% at the high- and low-N levels, respectively. The N x CO_2 interaction was not significant at the 5% level. In the 1993-1994 wheat study, where water instead of N level was the other variable, no CO_2 x H_2O interaction was observed.

INTERPRETATIONS: Significantly larger soil CO_2 fluxes were found in the high- than the low-N treated wheat plots. Fertilization promoted the increase in activities of soil microbial and root respiration. CO_2 enrichment further promoted this increase in activity. We would expect higher soil CO_2 fluxes from high-nutrient than low-nutrient soils where water is not limiting.

FUTURE PLANS: We plan to continue the soil CO_2 flux measurements in the FACE wheat study in the 1996-1997 crop year. Support will also be provided for obtaining soil CO_2 and other gas samples and for gas analysis and fluxes for the ensuing modelling studies that depend upon these inputs.

COLLABORATORS: S. Leavitt, University of Arizona, Tucson, AZ.

Table 1. Statistical analysis of the CO_2 and nitrogen (N) enrichment treatment effects on soil CO_2 flux.

Source of Variation	df	Sum of Squares	Mean Square	F-value	Pr > F
Model	12	47.3536	3.9461	4.55	0.0001
Error	131	113.6230	0.8764		
Corrected error	143	160.9766			
Source of Variation					
Rep	3	7.4946	2.4982	2.88	0.0384
CO_2	1	13.3834	13.3834	15.43	0.0001
Rep*CO_2	3	6.6458	2.2152	2.55	0.0582
N	1	16.7417	16.7417	19.30	0.0001
Rep*N	3	1.0096	0.3366	0.39	0.7618
CO_2*N	1	2.0784	2.0784	2.40	0.1240

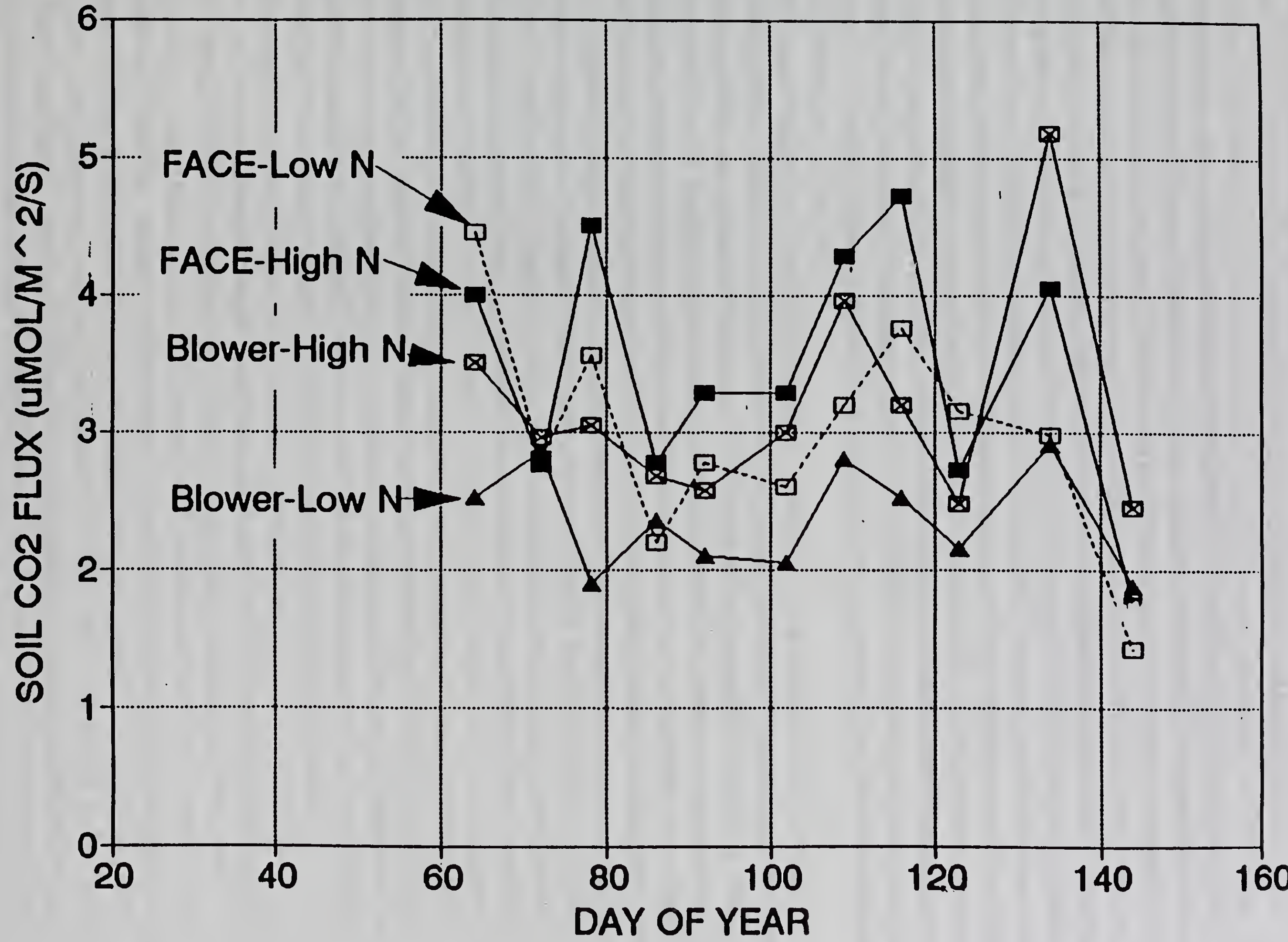

Figure 1. Soil CO_2 fluxes for the various CO_2- and N-enrichment combinations at different periods of wheat cultivation.

FACE 1995-96: EFFECTS OF ELEVATED CO_2 AND SOIL NITROGEN ON GROWTH AND YIELD PARAMETERS OF SPRING WHEAT

P. J. Pinter, Jr., Research Biologist; B. A. Kimball, Supervisory Soil Scientist; G. W. Wall, Plant Physiologist; R. L. LaMorte, Civil Engineer; F. J. Adamsen, Soil Scientist; and D. J. Hunsaker, Agricultural Engineer

PROBLEM: Rising concentrations of atmospheric CO_2 have many potential consequences for world agriculture. These range from modification of short-term radiation, water, and nutrient use efficiencies, to long-term biogeochemical alteration of the soils of agroecosystems as a whole. Free Air CO_2 Enrichment (FACE) experiments have been used since 1989 to test the responses of cotton and spring wheat to elevated CO_2 and water stress conditions. Compared with ambient controls, exposure to 550 µmol µmol^{-1} CO_2 for the entire season resulted in an average increase of 40% in cotton lint yield and 10% in wheat grain yield when water was not limiting. When water stress was imposed on the plants, CO_2 stimulated productivity even more. In less developed countries and in most natural ecosystems, nutrient availability is also expected to play a major role in affecting plant response to elevated CO_2. Thus, during the 1995-96 growing season, a series of experiments were begun to test the interactive effects of elevated CO_2 and nutrient fertilizer on the responses of spring wheat. This report furnishes preliminary observations on the effect of CO_2 and nitrogen on growth and yield responses of wheat grown under the realistic field conditions provided by the FACE experimental facility.

APPROACH: Experiments were conducted at the University of Arizona Maricopa Agricultural Center (MAC), south of Phoenix, Arizona. A hard, red, spring wheat (*Triticum aestivum*, L. cv Yecora Rojo) was sown on December 14-15, 1995 in EW oriented rows that were spaced 0.25 m apart. The seeding rate (109 kg ha^{-1}; ~236 seeds m^{-2}) and plant density at emergence (189 plants m^{-2}) were similar to those obtained in the 1993-94 FACE experiment. Irrigation was based on consumptive use requirements of the plants that were determined from estimates of daily potential evaporation multiplied by an appropriate crop coefficients for wheat. The crop received about 600 mm of water via subsurface (drip) irrigation and 39 mm rainfall during the season.

Plants were exposed to control (this year referred to as the BLOWER treatment, ~360 µmol µmol^{-1}) and enriched (FACE, ambient plus 200 µmol µmol^{-1}) CO_2 levels; treatments were replicated four times. Plots were positioned in field locations that had not been used for previous FACE studies. Enrichment began on Jan 1,1996, 2 days after 50% emergence of wheat seedlings and continued 24 hours a day with minimal interruptions until May 15, 1996. Unlike previous years' experiments, the control treatments during FACE 95-96 were equipped with blowers and airflow that provided microturbulent wind conditions more similar to those in FACE treatments. Two replicate plots were established in a different portion of the field to serve as ambient comparison treatments. These AMBIENT plots did not have blowers and thus were analogous to the CONTROL treatments of FACE92-93, and FACE 93-94. CO_2 treatment plots were split to test High (350 kg season^{-1}) and Low (70 kg season^{-1}) soil nitrogen levels on plant response. Nitrogen was delivered via the drip irrigation system at four times during the season: mid-tillering, stem extension, anthesis, and early grain filling stages of development.

Approximately 24 plants were sampled from all replicates of each treatment at ca. 10-day intervals. Plant phenology, green leaf and green stem were measured on a subsample of 12 median-sized plants. Crown, stem, green and nongreen leaf, and head components of all 24 plants were separated and dried for biomass determinations. Green leaf area index (GLAI) was computed from specific leaf weights from the subsample plants and the biomass of all 24 plants. After DOY 90, developing grains were separated from chaff by a combination of hand and machine threshing of heads that were pooled by subplot. Final grain yield was determined by harvest of approximately 20 m^2 area of each plot on May 29-30, 1996. Grain was oven-dried for 14 days at 70 °C. Yield data were analyzed using the ANOVA GLM procedures of the Statistical Analysis System (SAS Institute, Inc.). A split-plot model was used that included CO_2 (main plot), nitrogen (split plot), replication, and appropriate interaction terms.

FINDINGS: Plants exposed to the HIGH N had total biomass (fig. 1a) and GLAI (fig. 2a) values that were similar to those observed for WET treatments in previous FACE wheat experiments when N supply was also adequate. Total biomass of FACE HIGH N plants remained 15 to 20% higher than in the BLOWER HIGH N treatment from late February through mid-April (fig. 1b). Plants in the FACE LOW N treatment also were larger than BLOWER HIGH N plants for much of the season. Differences between GLAI of HIGH and LOW N plants first began to appear in late February, about 4 to 5 weeks before consistent differences could be observed in total biomass. Elevated CO_2 conferred about a 5-10% mid-season advantage in GLAI (fig. 2b). However, the stimulation was not as long-lasting as that observed for total biomass. In sharp contrast with earlier FACE experiments, plant senescence (as indicated by late season decline in GLAI) was not accelerated by elevated CO_2 when nitrogen was not limiting. There was only a slight increase in senescence rates caused by CO_2 in the LOW nitrogen treatment.

Overall, the final grain yields in the HIGH N plots were high and similar to yields from the WET treatments during the two previous FACE experiments (fig. 3). Compared with yields from BLOWER equipped plots, elevated CO_2 increased grain production by 15% in the HIGH N treatment; the increase was 12% in the LOW N treatment. ANOVA revealed that the differences between CO_2 treatment means were statistically significant at $p=0.06$. The LOW N treatment reduced grain yields by an average of 23% ($p<0.01$). The interaction between CO_2 and N was not statistically significant ($p=0.39$). Plants in the AMBIENT treatments had grain yields that were 5% and 17% higher than their respective BLOWER counterparts. Considerable yield variability was observed among the replicates within each treatment. We suspect this may have been caused by soil variation in different parts of the field.

INTERPRETATION: Our results show that the effects of elevated CO_2 on biomass and final yield under non-limiting nutrient and water conditions were only slightly higher during the 1995-96 growing season than for the first two years of FACE experimentation. Given the variability observed among the replicates, this small difference is unlikely to be statistically significant and may have been partially caused by the different CO_2 set point (i.e., +200 $\mu mol\ mol^{-1}$ above ambient). An interesting finding under low nitrogen conditions was that CO_2 still provided a large stimulation in biomass and a moderate increase in grain yield. Unlike the first 2 years of experimentation, where yields were reduced by water deficit and the effect of CO_2 seemed amplified, CO_2 seems to have a smaller effect when nitrogen shortage was responsible for reduced productivity. Given that the LOW N treatment reduced yields by only 23%, it is conceivable that reducing N still further will have a negative impact on stimulation by CO_2.

The AMBIENT plots out-yielded their BLOWER counterparts by 5% in the HIGH N and by 17% in the LOW N treatments (fig. 4). However, unlike the replicates of BLOWER and FACE, both replicates of the AMBIENT treatment plots were clustered in the northeast quadrant of the 8-ha field, where yields were above average. Inasmuch as this violates the experimental and statistical design, it is not possible to conclude whether the differences in yield could have been caused by a microclimatic effect of the BLOWERS themselves. Nevertheless, that possibility exists. And given the other evidence (i.e., elevated nighttime temperatures, faster dew dissipation, and accelerated phenology/senescence in BLOWER compared with ambient arrays), it appears that using BLOWER controls in the experiment was a prudent decision.

FUTURE PLANS: Analysis of these data is continuing. A FACE experiment with similar experimental protocol is planned for the 1996-97 wheat growing season.

COOPERATORS: Many individuals and agencies played important roles in this research. The authors wish to acknowledge the collaborative efforts of Steve Leavitt, University of Arizona, Bob Roth and Pat Murphree from the Maricopa Agricultural Center, and scientists from the Potsdam Institute for Climate Research. We also thank M. Baker, C. Farrugia, D. Langhorst, P. Novak, and C. O'Brien for technical assistance in processing the plant samples.

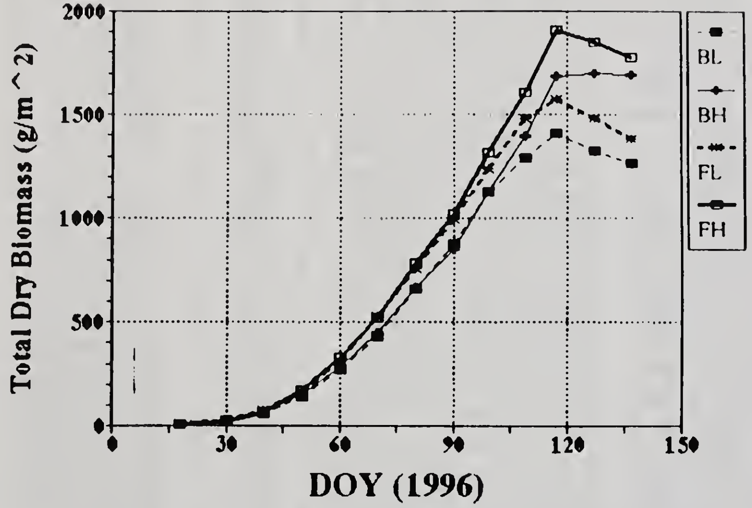

Figure 1a. Total dry biomass (g/m ^ 2) of Yecora Rojo wheat during the 1995-96 FACE experiment at Maricopa, AZ. (BL=Blower Low N; BH=Blower High N; FL=FACE Low N; FH=FACE High N. Data were smoothed using a 3 date moving average.

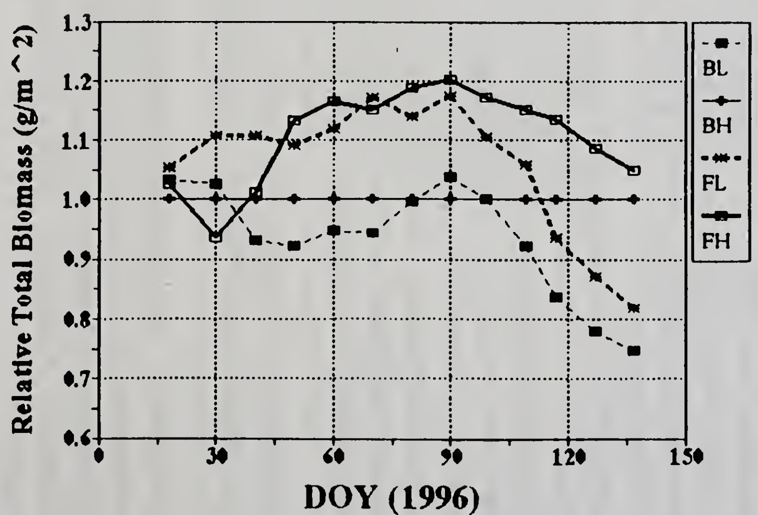

Figure 1b. Total dry biomass of Yecora Rojo wheat relative to values obtained for the Blower High N treatment. Abbreviations same as in fig. 1a.

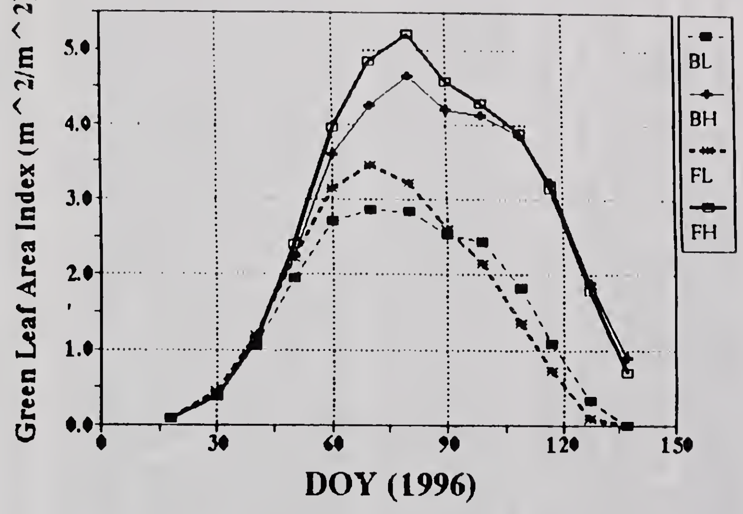

Figure 2a. Green leaf area index (m ^ 2/m ^ 2) of Yecora Rojo wheat during the 1995-96 FACE experiment at Maricopa, AZ. (BL=Blower Low N; BH=Blower High N; FL=FACE Low N; FH=FACE High N. Data were smoothed using a 3 date moving average.

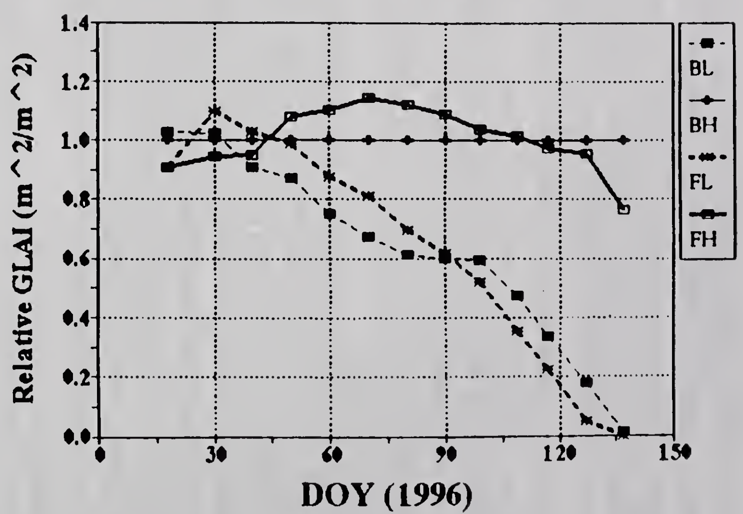

Figure 2b. Green leaf area index of Yecora Rojo wheat relative to values obtained for the Blower High N treatment. Abbreviations same as in Fig. 2a.

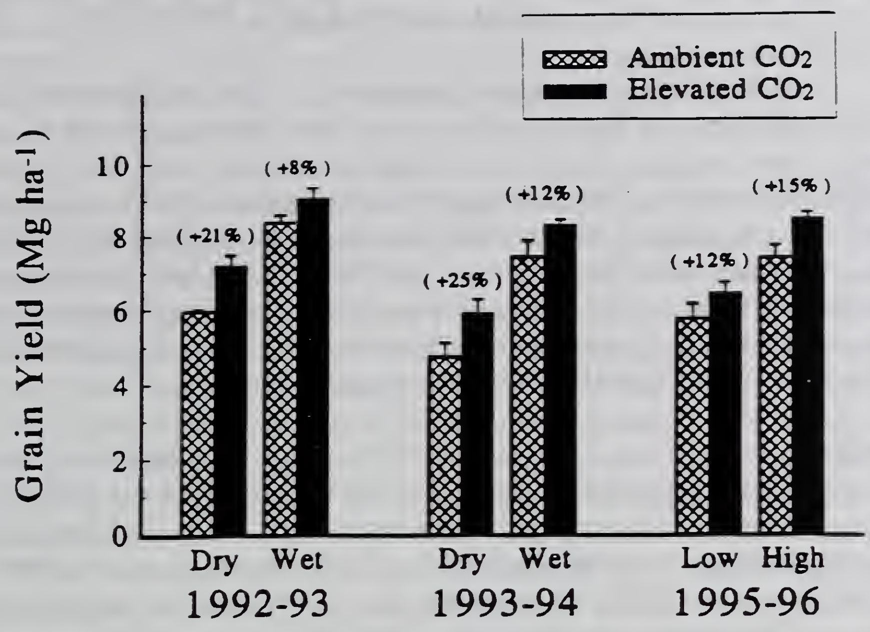

Figure 3. Summary of final harvest yields for 3 FACE wheat experiments conducted at MAC between 1992 until 1996. Percentages in parentheses above bars indicate relative enhancement by CO_2.

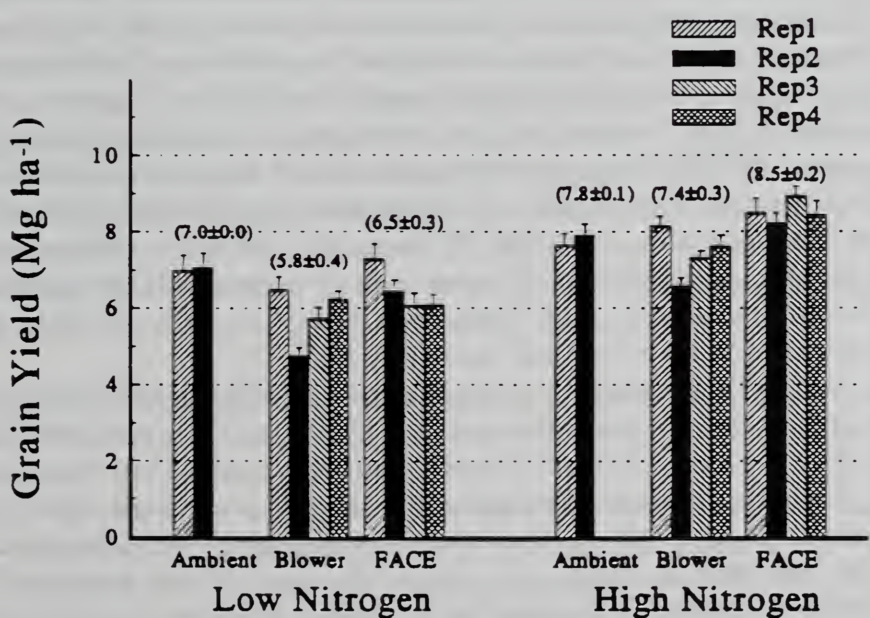

Figure 4. Final harvest yield data from the 1995-96 FACE experiment at MAC. Data are shown for individual replicates. Values given in parentheses represent mean and std error for each treatment.

WHEAT EVAPOTRANSPIRATION AS AFFECTED BY ELEVATED CO_2 AND VARIABLE SOIL NITROGEN

D. J. Hunsaker, Agricultural Engineer; B. A. Kimball, Supervisory Soil Scientist; P. J. Pinter, Jr., Research Biologist; G. W. Wall, Plant Physiologist; and R. L. LaMorte, Civil Engineer

PROBLEM: The earth's rising atmospheric carbon dioxide (CO_2) concentration is expected to impact agricultural crop production worldwide. One concern is how increased levels of atmospheric CO_2 in the future will affect crop evapotranspiration (ET) and, thus, crop water requirements and irrigation management in the future. To date, only a few research studies have quantified ET for crops exposed to elevated CO_2 under natural, open-field conditions. Our objective was to evaluate crop ET, using soil water depletion measurements, for wheat grown with CO_2-enriched air and variable soil nitrogen supply.

APPROACH: A Free-Air CO_2 Enrichment (FACE) system was installed in a 9-ha field site at The University of Arizona Maricopa Agricultural Center to study the effects of elevated CO_2 on crops cultivated in an environment representative of future agricultural fields. The 1995-6, FACE wheat experiment commenced with planting of Yecora Rojo, a spring wheat cultivar, on December 14 and 15, 1995, in flat beds at 0.25-m row spacings. As in previous FACE wheat studies, the FACE system was installed to enrich the atmospheric CO_2 concentration of four 25-m diameter circular plots (FACE plots) by 200 μmol mol^{-1}, (above 360 μmol mol^{-1}). Details on the FACE system design, construction, and operation were previously reported in the 1992 through 1995 USWCL "Annual Research Reports." Four circular control plots were also installed in the field, each plot approximately 90 m due east or west of one FACE plot, and were equipped with blowers to provide air movement across the plots similar to that in the FACE plots. However, these plots (designated Blower plots) were not enriched with CO_2.

The FACE experimental design was a strip-split-plot with CO_2 the main effect, replicated four times. Each of the eight circular main plots was split into two semicircular subplots, where one subplot (designated High N) received an adequate supply of nitrogen fertilizer during the season while the other subplot (designated Low N) received 20% of the adequate supply. All treatments were given 30 mm of water, applied by a portable sprinkler system on December 21, 1995, to moisten the seed bed for germination. Following crop establishment, subplots were irrigated with a subsurface drip system installed 0.18-0.25 m below the soil surface at 0.5-m spacings between drip tubes. Irrigation scheduling for the wheat crop was determined with a meteorologically-based crop water use model (AZSCHED) developed by The University of Arizona Agricultural and Biosystems Engineering Department. Water applications were given to all subplots at approximately 30% soil water depletion of the crop root zone as determined with AZSCHED. Water application depths were the same in both High and Low N treatments until May when less water was applied to the Low N treatments to match the earlier senescence of that treatment. Several nitrogen chemigation applications during the season provided a total of 350 kg ha^{-1} N for the High N treatment. The Low N treatment received 70 kg ha^{-1} N.

Soil water contents were measured in all subplots on 37 days between December 18, 1995, and May 16, 1996. Time-Domain-Reflectometry equipment was used to measure soil water content in the top 0.3-m soil profile. Subsurface soil water contents (from 0.4 m to 2.0 m) were measured with a neutron scattering device in 0.2-m increments. Soil water contents were measured in subplots every four to nine days through February 1996. During March through May 1996, soil water contents were generally measured immediately prior to an irrigation and again two days after the irrigation. Average daily wheat ET was determined by the change in soil water storage over the active rooting depth divided by the number of days between soil water measurements. However, only those soil measurement sampling periods where water was not added by irrigation or heavy rainfall were used for average daily ET calculations. Average daily wheat ET during periods when irrigation or rainfall occurred was estimated from the average daily ET calculations made before and after the period.

FINDINGS: Water applied from irrigation (including the initial 30 mm for crop establishment) totaled 650 mm for the High N and 590 mm for the Low N treatments. Total seasonal rainfall was about 40 mm. Soil water content means for all treatments (fig. 1) were high over the entire season, varying from about 55-60% available to above field capacity. The FACE-High treatment generally had a slightly higher mean soil water content than the Blower-High treatment during the season, while the Blower-Low treatment had a higher mean soil water content than the FACE-Low treatment. Soil water content means for the High N treatment were higher than those of the Low N treatment for most of the season although the relative difference in soil water content means between High and Low N treatment was gradually diminished as the season progressed.

Differences in the average daily wheat ET due to CO_2 for periods during the season were not statistically significant at 0.10 probability except for the two periods shown in figure 2. Average daily ET for the FACE-High treatment did not decrease more rapidly than that for the Blower-High treatment late in the season (May). Average daily ET for the Low N treatment was significantly lower ($p<0.10$) than that for the High N treatment after mid-March 1996. The error bars drawn upward from the mean average daily ET for the Low N treatment (fig. 2) represent the statistical least-significant-difference at 0.10 probability associated with the nitrogen effect. Regression of the average daily ET values (including May data) for the FACE-High treatment with the Blower-High treatment (fig. 3) resulted in a regression slope equal to 1.0. This indicated that there was not a seasonal effect on wheat ET due to CO_2 enrichment under well-fertilized conditions. For the Low N treatment, regression of the data (fig. 4) resulted in a slope of 1.02, which also indicated that there was no seasonal effect on wheat ET due to CO_2 enrichment under insufficient soil nitrogen. The estimated total seasonal ET was nearly equal for FACE-and Blower-High nitrogen treatments with seasonal ET values of 646 and 650 mm, respectively. Total seasonal ET for the Low nitrogen treatment was 514 and 494 for the FACE and Blower treatments, respectively. Analysis of variance indicated no effect on seasonal ET due to CO_2 ($p<0.47$), a significant effect due to soil nitrogen ($p<0.01$), and no interaction effect ($p<0.37$).

INTERPRETATION: The 1995-6 results indicated no change for average daily and total seasonal wheat evapotranspiration due to elevated atmospheric CO_2 concentration under both soil nitrogen managements. This finding differed somewhat from soil water balance ET results determined during earlier FACE wheat studies in 1992-3 and 1993-4. In the previous studies, seasonal wheat ET under well-watered and well-fertilized conditions (i.e., similar conditions for the High nitrogen treatments of 1995-6) was 4-5% lower in the FACE than control treatment. In addition, there was a significant reduction in daily ET for FACE plots that began about three weeks prior to harvest. However, in the earlier studies, because control plots were not equipped with blowers, FACE plants averaged 0.6 C warmer than control plants, all season long. This temperature rise may have caused earlier maturity for FACE. As expected, low soil nitrogen caused a significant reduction in daily wheat ET during much of the growing season that resulted in a 20-24% reduction in the total seasonal ET in 1995-6. The wheat ET response to low nitrogen was similar to the wheat ET response to limited irrigation water during 1992-3 and 1993-4.

FUTURE PLANS: CO_2 and soil nitrogen effects on wheat will be evaluated in a FACE wheat experiment to be conducted during the 1996-7 season. Wheat ET will again be determined from soil water measurements.

COOPERATORS: See FACE cooperator listing in the 1996 USWCL "Annual Research Report" entitled "Progress and Plans for the Free-Air CO_2 Enrichment (FACE) Project," by B.A. Kimball, et al.

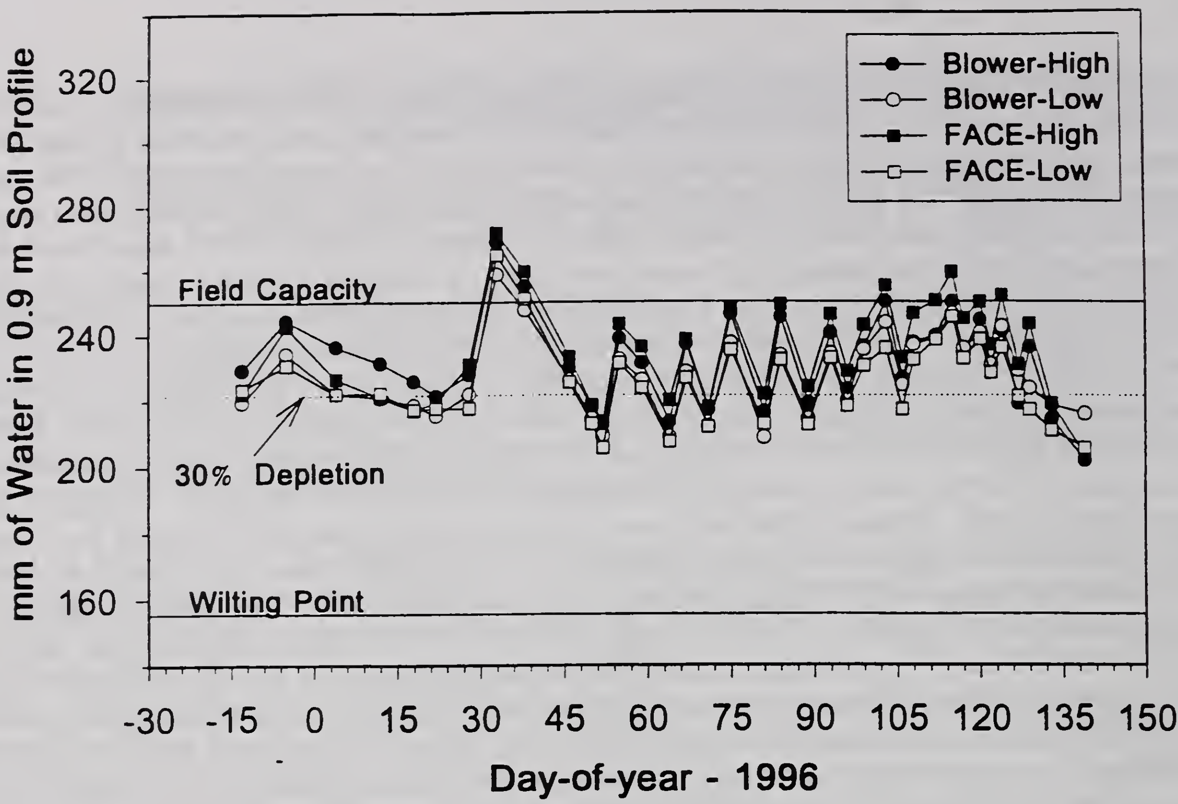

Figure 1. Soil water content (expressed as mm of water within a 0.9-m soil profile) treatment means with day of year in 1995-6.

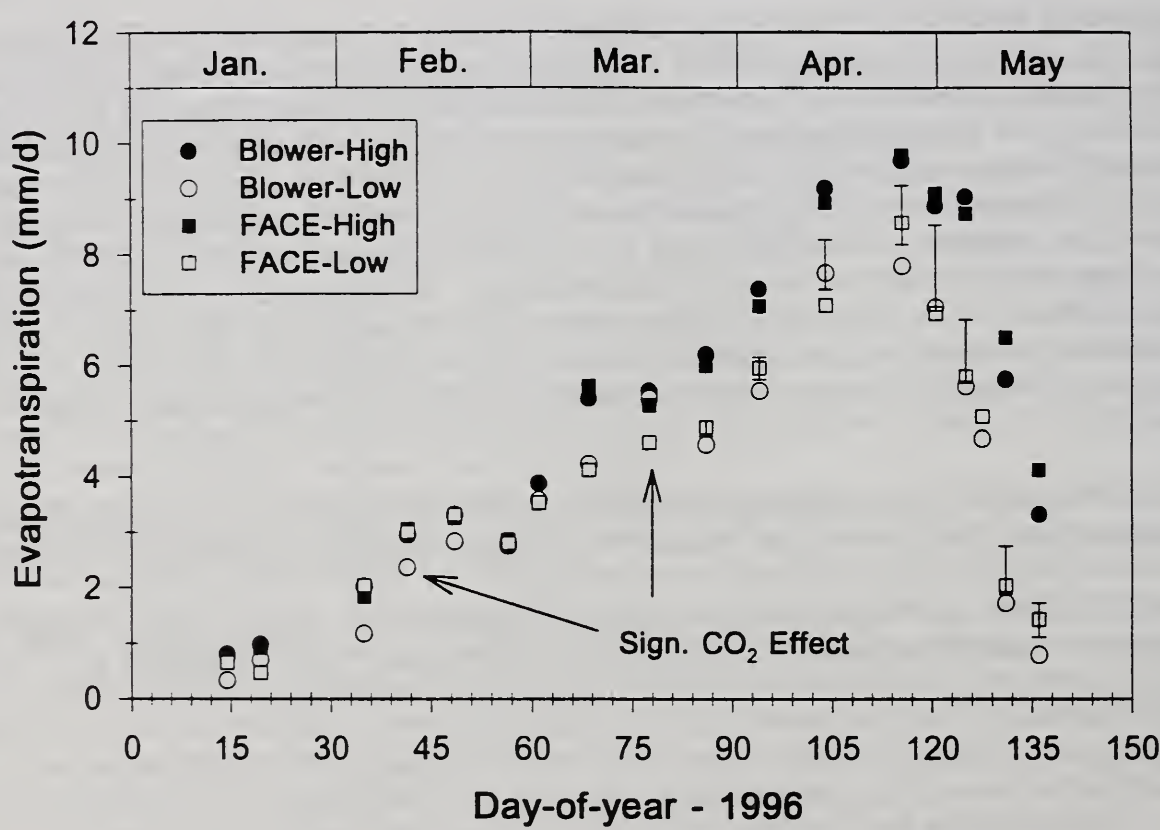

Figure 2. Daily evapotranspiration treatment means with day of year in 1995-6. The error bars drawn upward from the mean value of the Low nitrogen treatment represent the least-significant-difference value at the 0.10 probability associated with the nitrogen effect.

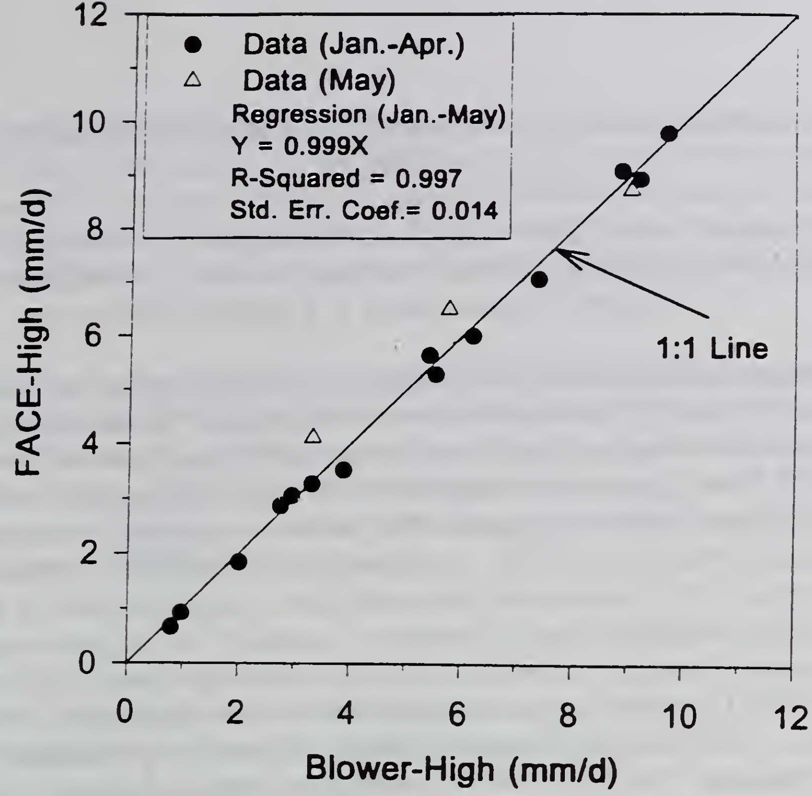

Figure 3. Regression results of the daily ET values for the FACE-High treatment from figure 2 with corresponding values for Blower-High, 1995-6.

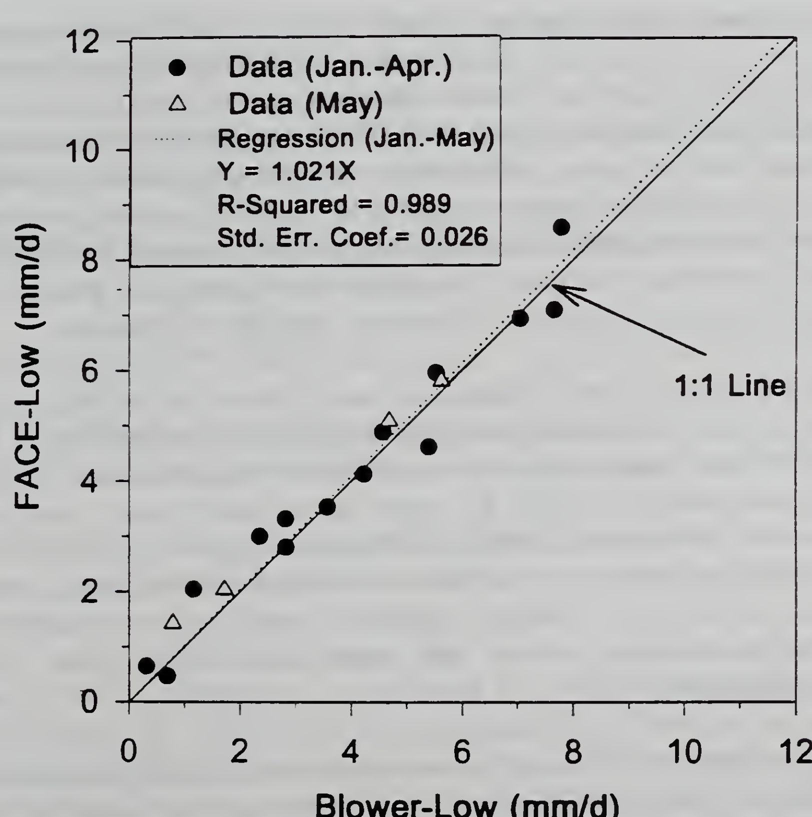

Figure 4. Regression results of the daily ET values for the FACE-Low treatment from figure 2 with corresponding values for Blower-Low, 1995-6.

EFFECTS OF NITROGEN AND CO_2 ON CANOPY ARCHITECTURE AND GAS EXCHANGE IN WHEAT

T. J. Brooks, Graduate Student; G. W. Wall, Plant Physiologist; P. J. Pinter Jr., Research Biologist; B. A. Kimball, Soil Scientist; A. Webber, Assistant Professor; D. Clark, Associate Professor; T. Kartschall, Physicist; and R. L. LaMorte, Civil Engineer

PROBLEM: The Intergovernmental Panel on Climate Change (IPCC) reports that global CO_2 levels will rise from the current ambient level of 370 μmol mol^{-1} to over 500 μmol mol^{-1} by the end of the 21st century (IPCC, 1995). Of primary concern to the human population is the impact that rising global CO_2 concentrations will have on agriculture. The U.S. Water Conservation Laboratory's (USWCL) Environmental and Plant Dynamics (EPD) group has been investigating the impact of increased CO_2 and water stress on various agricultural crops for the past 8 years through the use of Free-Air CO_2 Enrichment apparatus (FACE) (Hendrey, 1993; Hendrey and Kimball, 1994). Previous FACE experiments used small (1m^2) pop-on chambers to measure the rates of net photosynthesis and canopy conductance, thereby providing "snapshots" of crop physiology. Results from these investigations have enabled members of the EPD group to conclude that canopy photosynthesis and water use efficiency are improved in C3 plants, such as wheat and cotton, when subjected to CO_2 enriched environments (Kimball et al., 1995). The net effect of these CO_2-based responses are substantial increases in yield with slightly less water consumed. The FACE 1995-6 investigation seeks to determine if water conservation and improved plant growth will hold true when wheat is grown under CO_2-enriched conditions with limiting soil nitrogen. Of particular interest are the effects of canopy architecture as related to variable light environments on canopy photosynthesis. It is our objective to quantify these relationships and relate them to individual leaf photosynthetic rates.

APPROACH: Four 25-m-diameter rings were placed in the field and used continually to enrich the CO_2 concentration of the air to 200 μmol mol^{-1} above ambient. Four identical rings served as controls. Ample nitrogen was applied to one-half of each ring, while the other half was subjected to nitrogen stress (strip-split plot design). "Flow-through" chambers (based on Garcia, 1990) were placed in each treatment for one of the four replicates and were used to collect canopy carbon and water exchange data for a period of 72-96 hours. The chambers were moved from replicate to replicate throughout the course of a growing season. Resulting data were analyzed for differences in both diurnal and temporal trends in canopy photosynthesis. Supplemental measurements of canopy greenness, mean leaf tip angle distribution, and plant area index aided in generating a general understanding of canopy architecture, development, and light environments.

FINDINGS: At mid-season, when canopy differences were greatest, but not yet confounded by senescence effects, CO_2 enrichment enhanced whole-canopy daily carbon accumulation by 9% (fig. 1). Canopies grown under reduced nitrogen had a 6% reduction of whole-canopy daily carbon accumulation. CO_2 enrichment enhanced individual leaf carbon accumulation by 37% (fig. 2). Leaves grown under reduced nitrogen had a 24% reduction of individual leaf carbon accumulation. Nitrogen-stressed canopies were less dense and had leaf angle distribution patterns more characteristic of erectophiles, whereas nitrogen-unlimited canopies had more planar leaf angle distribution patterns (fig. 3). Because nitrogen-stressed canopies had more erectophile leaf angle distributions than nitrogen-unlimited canopies, light penetration to lower leaves appeared to be greater, particularly at lower zenith angles (fig. 4).

INTERPRETATION Architectural differences between nitrogen-stressed and nitrogen-unlimited canopies can, in part, explain the difference in the accumulation of carbon between an upper-canopy leaf and the whole-canopy. However, detailed analysis of canopy photosynthetic curves reveals that they are asymmetric in shape. If canopy architecture and zenith angle were the sole contributing factors to the observed effects, then the curves should be symmetrical, which suggests that perhaps another factor (s) was also contributing to differences between the canopy and leaf-based measurements. As a possible explanation, photoinhibition (Demmig-Adams, 1992;

Horton, 1994) of the upper-most canopy leaves may often occur during the mid-season when midday maximum light fluxes frequently exceeds 2000 μmol m^{-2} s^{-1} (400-700nm). If upper leaves are photoinhibited equally in all treatments, then the penetration of light into the sparse canopies would have a more profound effect than canopy structure alone and would serve to explain the relative lack of symmetry found in diurnal canopy photosynthesis curves. If confirmed, this photoinhibition-architecture effect indicates the potential for a CO_2-enrichment by latitude effect.

FUTURE PLANS: Canopy gas exchange will be measured for a second growing season. Additional research is being initiated to determine the specific protein, carbohydrate, and genetic mechanisms that may have contributed to these responses. Canopy greenness, plant area index, mean leaf tip angle distributions, and photoinhibition of upper canopy leaves will be measured more intensely to assist in understanding canopy architecture and movement of nitrogen within the plant. The data from these experiments will be released to climate modelers to increase model detail and accuracy.

COOPERATORS:

Arizona State University[1] - Dennis Clark and Andrew Webber.
Potsdam Institute for Climate Impact Research - Thomas Kartschall
University of Arizona - Steve Leavitt and Elise Pendall
U.S. Water Conservation Laboratory - Floyd Adamsen and Douglas Hunsaker.
Technical Support - Thomas Clarke, Laura Olivieri, Jason Biscombe, Bud and Laurie Lewis, and Dean Pettit.

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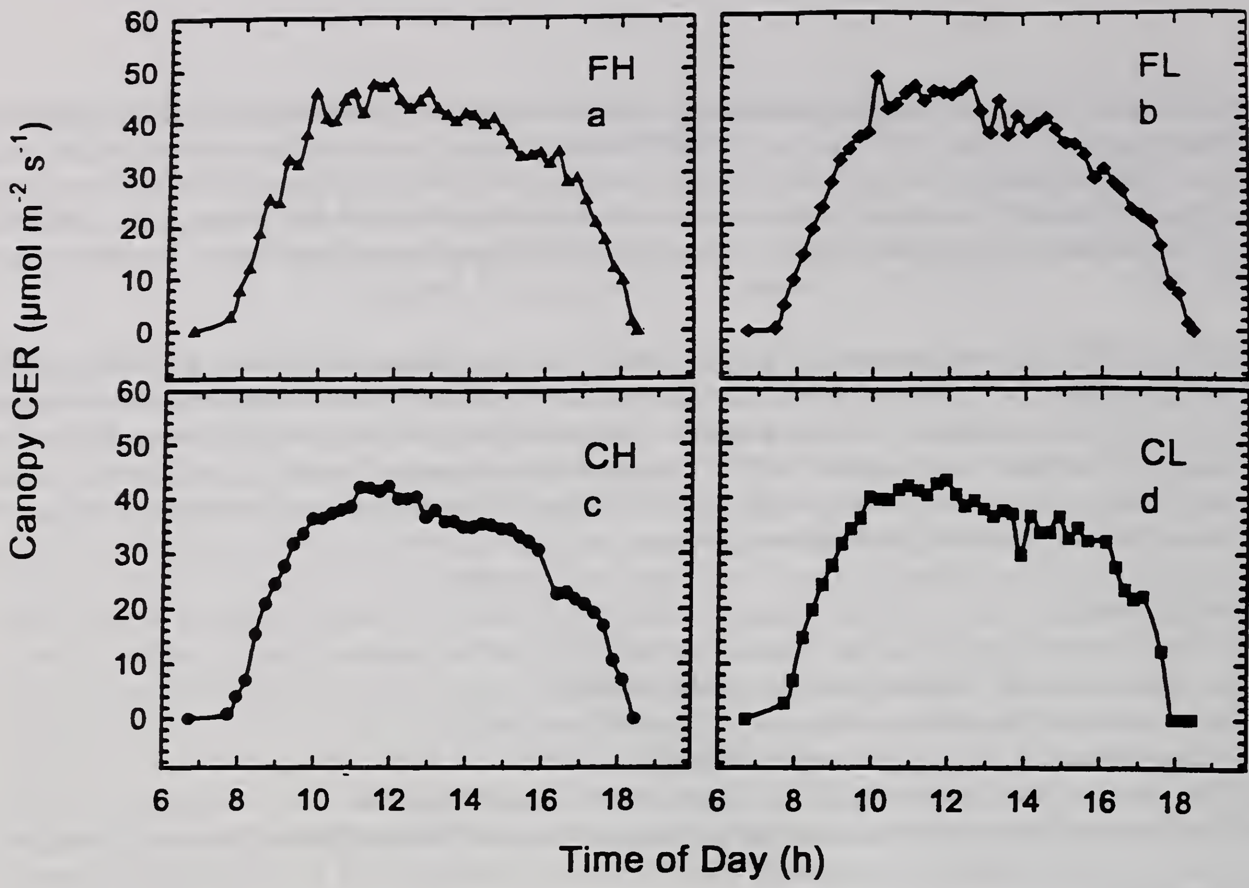
[1] **ACKNOWLEDGEMENT:** The first author would like to thank Profs. Stanley Zsarek and Leslie Towill for their mentorship and guidance.



Figures 1a-d. Diurnal canopy photosynthesis rates for day-of-year 063. FH (a) represents CO_2 enriched, ample nitrogen; FL (b) is CO_2 enriched, nitrogen stressed; CH (c) is ambient CO_2, ample nitrogen; and CL (d) is ambient CO_2, nitrogen stressed.

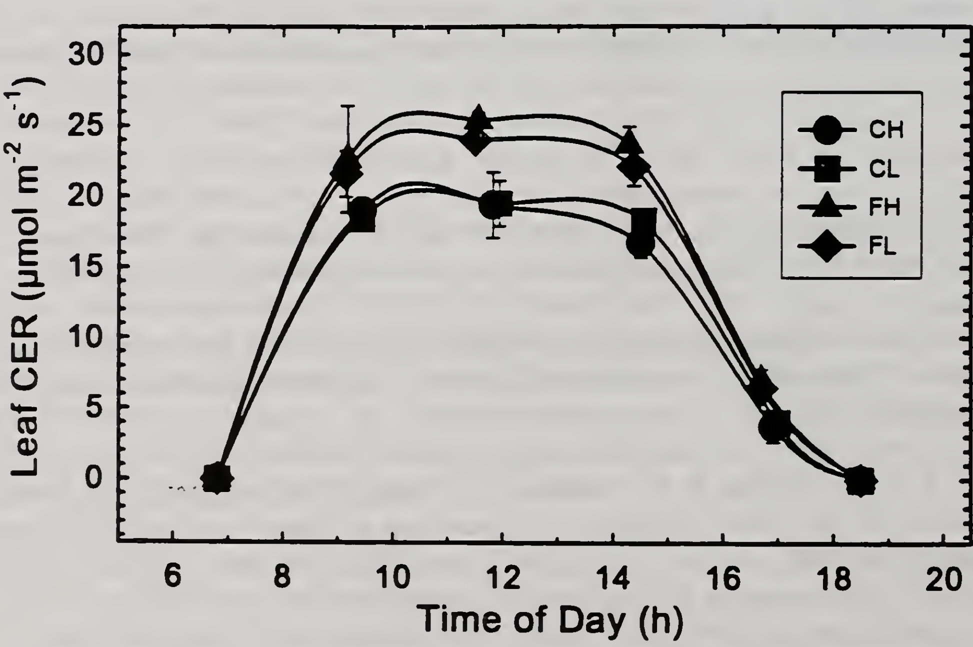


Figure 2. Diurnal leaf photosynthesis rates for day-of-year 067.

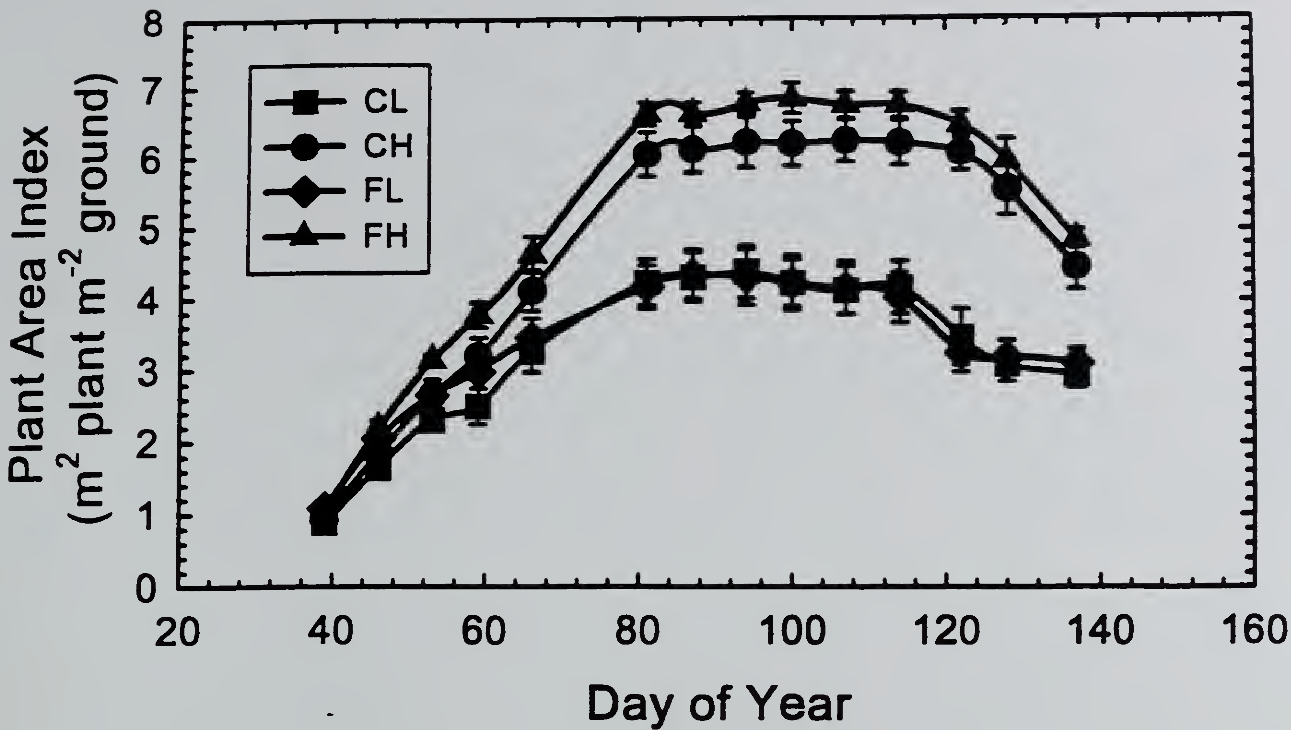


Figure 3. Temporal trends in plant area index. Measurements were made using the LAI-2000 (LI-COR Inc., Lincoln, NE) and include both green and brown stem and leaf material.

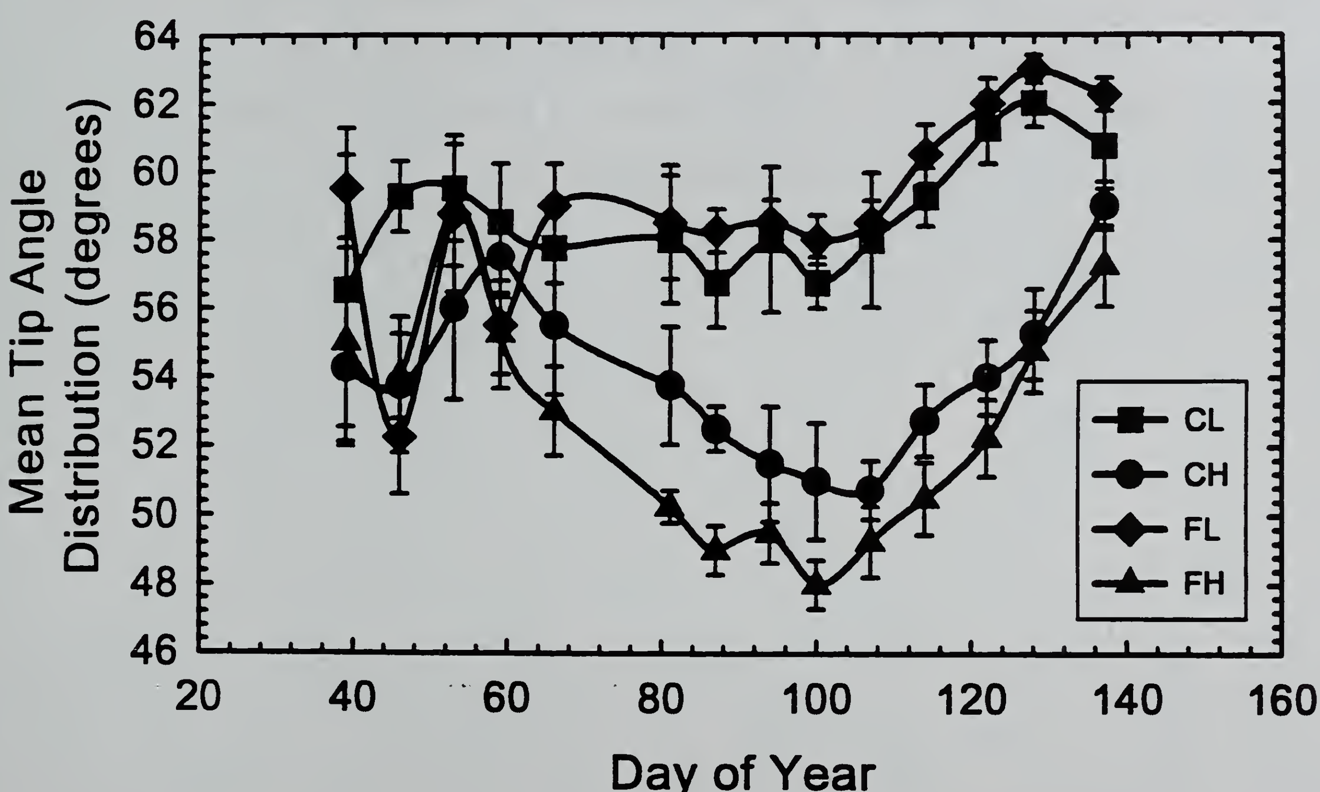


Figure 4. Temporal trends in leaf angle distribution. Measurements made using the LAI-2000 (LI-COR Inc., Lincoln, NE) include both green and brown leaf and stem material. Ninety degrees represents a leaf or stem perpendicular to the ground.

QUANTITATIVE REMOTE SENSING APPROACHES FOR MONITORING AND MANAGING AGRICULTURAL AND ENVIRONMENTAL RESOURCES

A SYNERGISTIC APPROACH TO ESTIMATING LEAF AREA INDEX WITH MODELS AND REMOTE SENSING DATA

J. Qi and M. S. Moran, Physical Scientists

PROBLEM: Vegetation density such as leaf area index (LAI) is an important measure of food production. Estimations of vegetation density will, therefore, provide vital information about yield production and help in policy making. Remote sensing techniques provide tools to monitor vegetation density and map its spatial distributions but are limited by the lack of physical links between LAI and remote sensing variables. In the past, estimations of LAI have relied on empirical relationships between LAI and vegetation indices, but these relationships cannot be generalized for operational applications to spatially distributed satellite images because those empirical coefficients are different from one type of vegetation to another. Recently, estimation of LAI values with remotely sensed data has been practiced by inverting canopy bidirectional reflectance distribution function models (Qi et al., 1995). This approach is also limited by difficulties in inverting models and excessive computing time. The objective of this research is to develop an operational technique to estimate LAI quantitatively, without these limitations.

APPROACH: A graphical presentation of this synergistic approach is illustrated in figure 1, where the vegetation index approach is combined with the modeling approach. In the first step, multidirectional remote sensing measurements and optional ancillary data are used as an input to a BRDF model for an inversion process. The remote sensing data set can be either of ground or aircraft, or subset of satellite images, while the ancillary data are optional. This step produces a set of parameters used in the model and the calculated vegetation indices (VI) from the input remote sensing data. In a second step, the intermediate output parameters such as LAI and the VI are then used in a statistical regression process. The regression process includes fitting curves of different equations (linear, exponential, power, and polynomial functions of LAI and vegetation indices). By examining the statistical merit such as the R^2, the best-fitting curve is selected as an optimal intermediate output ($LAI = f(VI)$). The purpose of this step is to reduce the computing time and to remove some outliers due to convergence failure or external noises. In a third step, the remotely sensed images were first used to calculated vegetation index values and then the optimal equation ($LAI\text{-}f(VI)$) was applied to convert the VI to LAI images. This synergistic approach was tested with Landsat and SPOT satellite images and ground LAI measurements at the USDA-ARS Walnut Gulch Experimental Watershed (WGEW) in southeastern Arizona.

FINDINGS: The proposed synergistic approach was successfully used to estimate regional LAI values (figure 2) using Landsat images acquired on the September 10, 1990. The dynamic range of estimated LAI values was from 0 to 3.3. The higher vegetation density areas were distributed along water channels where soil moisture was most likely highest because of surface run-off process. The estimated LAI values were compared with the ground-based LAI measurements made at eight meteorological stations in WGEW (figure 3). Although the measurements were made at a different time of the year, the estimated values were in close agreement with the measurements. The computing time of this approach was reduced by at least 80 percent when compared with the inversion-alone approach for an image of 512 by 512 size.

INTERPRETATION: In arid and semiarid environment like Arizona, a major use of water resources is for agriculture. Plant growth is almost entirely dependent on irrigation and; therefore, timely scheduling of irrigation and efficient use of water are key factors of determining plant health and ultimately the food production. Plant water stress, due to improper irrigation scheduling, will hinder the growth and result in reduction in plant density and yields. Timely monitoring of plant growth and its spatial distribution will consequently provide an important clue about water availability and its use efficiency. The proposed technique, along with satellite images, can provide timely spatial and temporal distribution of vegetation density, allowing early yield prediction and diagnostic analysis of the plant growth conditions for proper water and nutrient applications.

FUTURE PLANS: Although satisfactory results were obtained with the proposed technique, a sensitivity analysis is needed to investigate errors in estimated LAI due to noise in remote sensing images. This error analysis should be incorporated in the technique for operational applications.

COOPERATORS: Mark Weltz, USDA-ARS Southwest Watershed Research Center, Tucson, Arizona; Yann H. Kerr, Centre d'Etudes Spatiales de la BIOsphere (CESBIO), Toulouse, France; Soroosh Sorooshian, Department of Hydrology and Water Resources, The University of Arizona, Tucson, Arizona.

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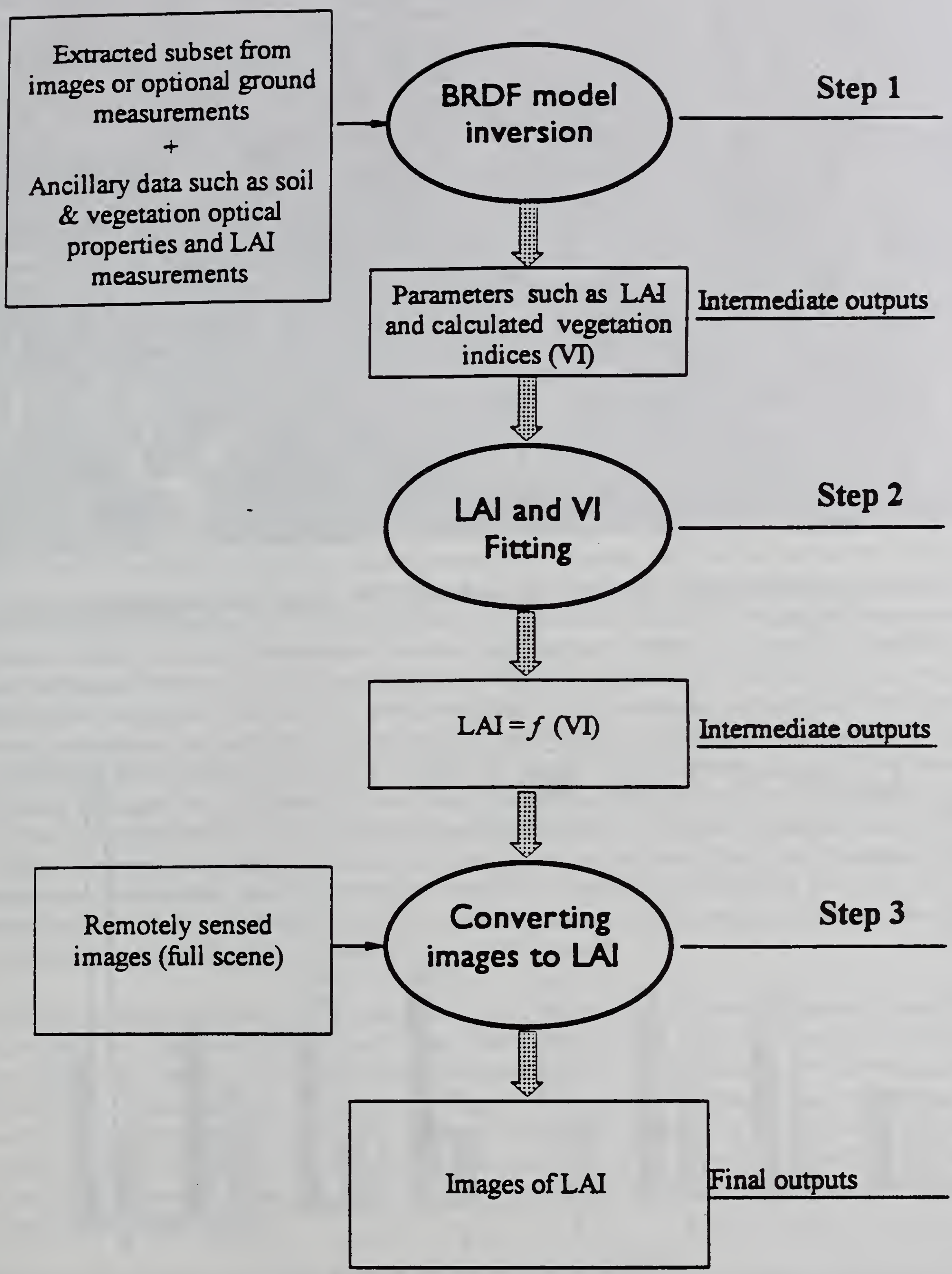

Figure 1. Graphic presentation of the synergistic approach to estimating LAI values with remote sensing images.

Figure 2. LAI map generated using the proposed approach with a TM image where bright areas are high LAI and dark areas are low LAI.

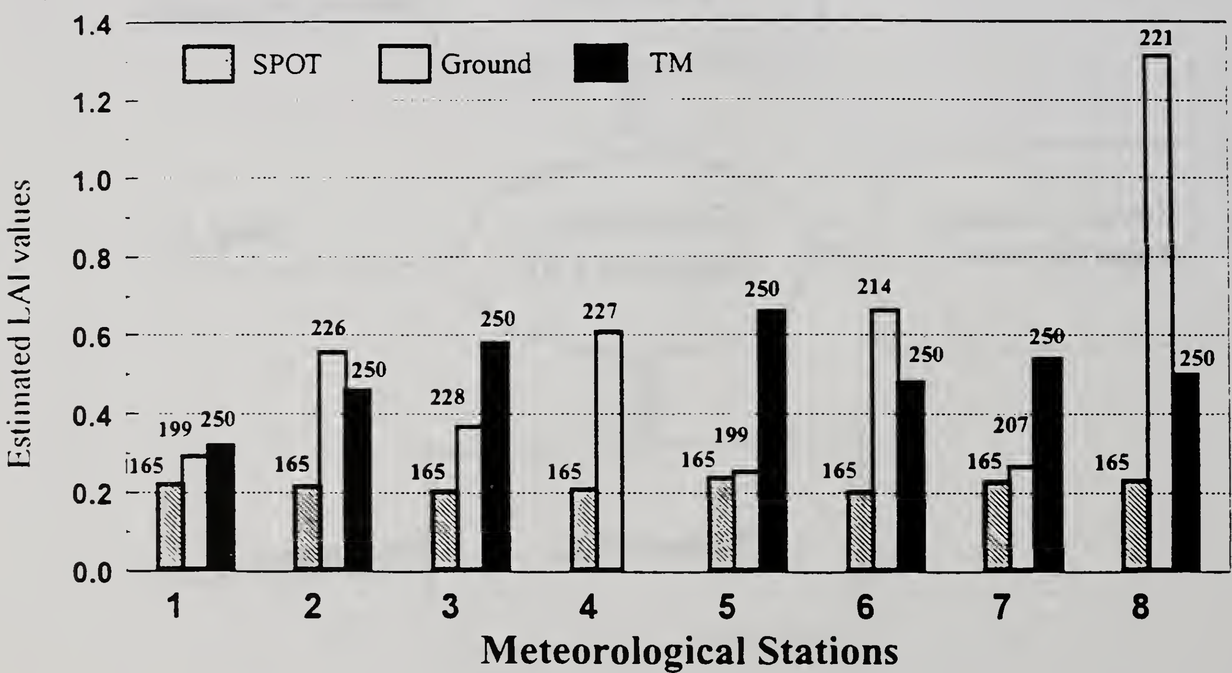

Figure 3. Comparison of estimated LAI with ground measurements at eight (8) meteorological stations. The numbers above each bar represent the day-of-year for each measurement.

DETERMINING EVAPORATION BY USING AN ATMOSPHERIC MODEL COUPLED TO LANDSAT TM DATA

J. J. Toth, Meteorologist; and M. S. Moran, Physical Scientist

PROBLEM: Sensible heat flux and evapotranspiration from the earth's surface are important for modeling long-term global change as well as for short-term agricultural decisions. For many years the ARS has estimated these quantities with remotely sensed data. Using a satellite image surface fluxes can be determined across a broad region. Meteorological data (temperature, moisture, wind) are a necessary input (fig. 1a). In areas of complex terrain (or other large-scale land-surface heterogeneities) the actual meteorological data can vary considerably. One solution is to have an atmospheric model analyze data fields that are consistent with the underlying surface (fig. 1b). On the other hand the atmospheric model also requires information about the surface characteristics. Until recently atmospheric models have specified these characteristics categorically, using a small (10-20) number of categories for the entire globe. A better approach would be to update the surface characteristics using the latest satellite data (fig. 1c). Under this project a two-way coupling between Landsat data and a mesoscale atmospheric model is being developed, with the goal of more accurately estimating evapotranspiration and sensible heat flux (fig. 1d).

APPROACH: The mesoscale model being used in this study divides the atmosphere into a horizontal mesh of grid cells. A vertical cross-section through just one of these grid cells is shown in fig. 1e. Above the earth's surface each cell contains atmospheric values of temperature, moisture, and wind, as well as the downward fluxes of short- and longwave radiation. At and below the surface each cell is subdivided into patches of water, bare soil, and vegetation/shaded-soil. Calculating the total sensible heat flux and evapotranspiration is, in essence, a matter of determining the temperature, moisture, and roughness length for each of the subdivisions. Model input parameters that bear on this determination include the surface albedo, the emissivity, the vegetation leaf area, the soil temperature and moisture, and the soil thermal and hydraulic conductivities. Previous sensitivity studies, considering the uncertainty in the range of each of these parameters, have shown that the moisture availabilities for the bare soil and for the vegetation are by far of most importance. Since these differ the vegetation coverage is also important. We are using Landsat data to adjust the most important parameters away from their categorical estimates. Specifically, the satellite normalized difference vegetation index (NDVI) is used to adjust the vegetation coverage. Then the satellite-derived surface temperatures are compared with the same temperature information from the model (a weighted average of the model's bare soil and vegetation temperatures). Mean temperature biases in the model are considered an indirect indication that the moisture availabilities need adjustment—for example, too warm is too dry

FINDINGS: After initial tests with two-dimensional simulations, the full three-dimensional coupled model with 4-km and 1-km grid-spacings was run for four mostly clear days in 1992. On these days the bare soil was undoubtedly dry, and so the moisture adjustment simplified to an adjustment of the vegetation stomatal conductance. These adjustments were fairly small and produced model temperatures in good agreement with the satellite thermal data, both in terms of temperatures averaged separately for each biome and in terms of the overall spatial variability. The model-generated evapotranspiration was compared with data from the ARS Walnut Gulch watershed. These also agreed reasonably well, especially after taking into account the uncertainties in the ground-measurements.

INTERPRETATION: The ability to produce variable surface temperatures that are consistent with the satellite thermal data lends some degree of confidence that the model-generated fields of spatially variable surface fluxes, in particular evapotranspiration, are reliable. Many rangeland areas are only partially vegetated, and each satellite pixel detects a combination of vegetation and bare soil. The bare soil temperatures can be significantly modified by variable wind speeds (for example, upstream vs. downstream from a mountain range). Estimates of rangeland evapotranspiration could be improved by using the coupled model to take such effects into account.

FUTURE PLANS: So far the model has been run for only short periods bracketing each Landsat overpass. Once the coupling algorithm is finalized, the model will be run continuously for a period of several weeks, using Landsat data on subsequent days to update the surface characteristics. Also, the model could be run for certain climatologically favored patterns. The results from these detailed simulations could be retrieved and used repeatedly on a routine basis.

COOPERATORS: D.C. Goodrich, ARS Southwest Watershed Research Center, Tucson, AZ; R. Avissar, Rutgers University, New Brunswick, NJ; A.F. Rahman, Univ. of Arizona, Dept. of Hydrology and Water Resources, Tucson, AZ; Electric Power Research Institute, Palo Alto, CA

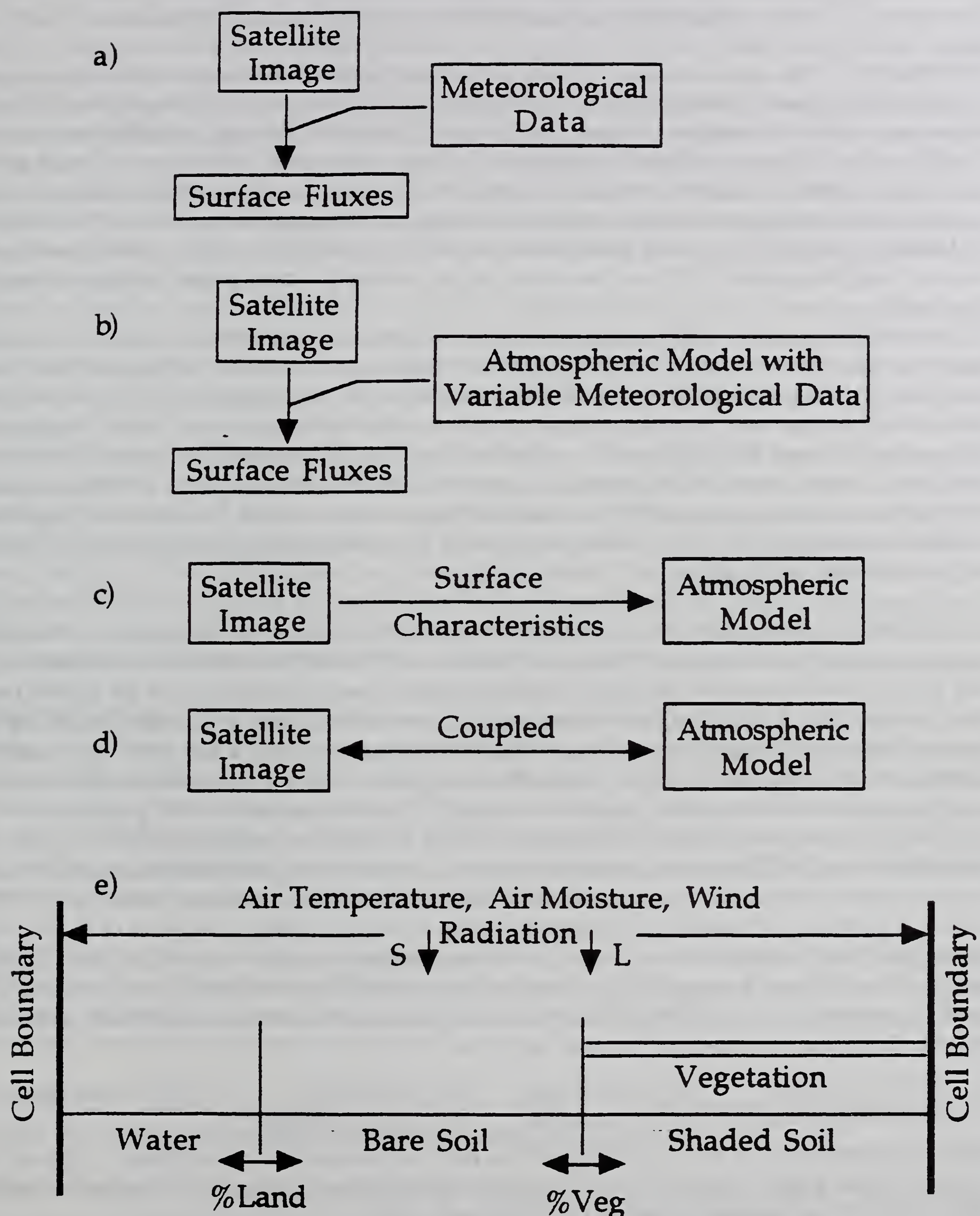

Figure 1. Components of the satellite-image/atmospheric-model coupled analysis tool.

CALIBRATION OF REFERENCE REFLECTANCE TARPS FOR USE WITH AIRBORNE CAMERAS

M. S. Moran, T. R. Clarke, Physical Scientists,
P. J. Pinter, Jr., Research Biologist, J. Qi, Physical Scientist

PROBLEM: With recent advances in multispectral video and digital cameras, there has been a surge in commercial companies offering aircraft-based digital images filtered to the visible and near-infrared (NIR) spectrum to agricultural customers for precision farming. This product becomes infinitely more valuable if the digital numbers (dn) can be converted to values of surface reflectance (ρ: the ratio of reflected and incident radiation at the surface) which are comparable over time for monitoring seasonal crop and soil conditions. One approach for converting dn to ρ has been to derive a linear regression equation between dn and ρ, based on targets of known ρ within the flight line of the airborne cameras. Commercially-available, chemically-treated canvas tarps of large dimensions (~8 x 8 m) have been used to provide the stable ground references needed for this approach.

The tarp calibration provided by commercial producers is a directional/hemispherical calibration measured with an integrating-sphere spectrophotometer system. Directional/hemispherical reflectance factor would be designated by ρ(θ/h), where the first parenthetical term refers to the view angle of the radiometer (where a view normal to the target is 0°) and the second term refers to the light source angle (where irradiance from a hemisphere is termed h). There is ample evidence that ρ(0°/h) differs from the reflectance measured in field conditions with the sun as the illumination source, termed directional/directional or ρ(0°/θ). Because of its dependence on incidence angle, ρ(0°/θ) is considerably more sensitive to the non-lambertian properties of the reference tarp than ρ(0°/h). Thus, a calibration equation for field deployment of such tarps must be derived as a function of solar zenith angle.

APPROACH: In 1995, scientists at several universities and USDA locations acquired a set of twelve 8 x 8 m reference tarps with a variety of ρ(0°/h) values from Tracor GIE (1652 W. 820 N., Provo, Utah 84601). One tarp (at ρ(0°/h)=0.32) was also chemically treated to provide a constant emissivity over the spectral range 8-12 µm. With each tarp, Tracor GIE agreed to provide a 2 x 2' swatch of the same canvas material treated in the same chemical solutions for calibration purposes. Each swatch was stapled to a 2 x 2' plywood board (of 1/4" thickness) that had been painted (3 coats) with a flat black paint. These board-mounted swatches were the right size for comparison with reference panels of known ρ(0°/θ) and for use with the field goniometer.

A field goniometer was used for this study to provide a calibration based on conditions similar to those encountered in the field; that is, the irradiance source was the sun and the calibration measurements were made with the same radiometer and data logger used for subsequent field measurements (Jackson et al., 1992). All swatches were cross-referenced to a Spectralon reference panel provided by Labsphere (P.O. Box 70, North Sutton, NH 03260) which had been calibrated in 1991 and then stored until it was used for this calibration. For each swatch, voltages were measured with a Modular Multispectral Radiometer (MMR) at several solar incidence angles ranging from 10° to 68°. The MMR was filtered to seven spectral bands, similar to the Landsat Thematic Mapper (TM) spectral bands:

b1) 0.45-0.52 µm,	b3) 0.63-0.69 µm,	b5) 1.15-1.30 µm,	b7) 2.05-2.30 µm.
b2) 0.52-0.60 µm,	b4) 0.76-0.90 µm,	b6) 1.55-1.75 µm and	

With the cross-reference to the calibrated Spectralon panel and the goniometer information of spectral voltages at 8 solar zenith angles, we derived fourth-order polynomial relations between ρ(0°/θ) and solar zenith angles from 10-68° for each swatch for each of i spectral bands, where

$$\rho(0°/\theta)i = a_{0,i} + a_{1,i}\theta + a_{2,i}\theta^2 + a_{3,i}\theta^3 + a_{4,i}\theta^4. \quad (1)$$

FINDINGS: We found that all swatches exhibited substantial non-lambertian behavior (e.g., Figure 1). Furthermore, the absolute values of $\rho(0°/\theta)$ and the non-lambertian characteristics of b5-b7 were substantially different from those of b1-b4. It was notable that, for b1-b4, $\rho(0°/45°)$ was close to Tracor-specified values of $\rho(0°/h)$. Whereas, for b5-b7, the difference between $\rho(0°/45°)$ and $\rho(0°/h)$ was a function of $\rho(0°/h)$. The swatch that was chemically treated for the property of constant emissivity had different $\rho(0°/\theta)$ properties than those of an untreated swatch of the same reflectance ($\rho(0°/h)$=0.32). This may have been due to the "sparkly" appearance of the constant-emissivity swatch in the sunlight.

The "shapes" of the calibration equations (normalized to a reflectance value of 1.0 at 45°) differed by band and by value of $\rho(\theta/h)$ (e.g., Figure 2). First, the greatest relative non-lambertian properties were associated with the swatches of lowest $\rho(0°/h)$. For swatches of $\rho(0°/h)$=0.04, the $\rho(0°/10°)$ was nearly 1.6 times $\rho(0°/45°)$. Second, the widening of the set of lines as angles deviated from 45° indicated that non-lambertian properties were different for different bands. The degree of "widening" differed by swatch, where the non-lambertian properties of swatches of $\rho(0°/h)$=0.32 were particularly uniform across all bands and those of swatches of $\rho(0°/h)$=0.48 were particularly non-uniform.

Because we had three swatches of $\rho(0°/h)$=0.04 and four swatches of $\rho(0°/h)$=0.48, it was possible to explore the potential for "general" calibration equations that could be applied to other tarps produced by Tracor GIE. We computed that a general calibration equation for tarps of $\rho(0°/h)$=0.48 and 0.04 would have uncertainties in all bands of $\rho(0°/\theta)<0.025$ and $\rho(0°/\theta)<0.006$, respectively. Since this uncertainty was far less than that associated with the non-lambertian behavior of the swatches, general equations were derived for tarps of $\rho(0°/h)$= 0.04, 0.08, 0.32, 0.32+ (plus emissivity treatment), and 0.48 (e.g., Figure 3). Such general equations will be useful for applications with tarps of the same $\rho(0°/h)$ values as those used in this study. However, it would also be useful to have a means of deriving reasonable calibration equations for tarps of *any* value of $\rho(0°/h)$. One approach would be to define relations between $\rho(0°/h)$ and corresponding values of the polynomial coefficients $a_{0,i}$ to $a_{4,i}$ from Eq. (1). We found a logical progression of the values of the coefficients with increasing $\rho(0°/h)$ that could be fit with a second-order polynomial with r^2 values greater than 0.95. Based on those equations, the coefficients $a_{0,1-4}$ to $a_{4,1-4}$ could be derived for any tarp of $0.04<\rho(0°/h)<0.48$. These calibration coefficients and the general calibration equations for each tarp are available by email request from moran@tucson.ars.ag.gov.

INTERPRETATION: We found that tarps such as those produced by Tracor GIE would be very useful for converting aircraft-based digital images to maps of surface reflectance based on general calibration equations for the visible/NIR wavelengths. However, since the non-lambertian properties of the tarps were substantial, calibration equations must be derived as a function of solar zenith angle. Care must be taken when using these tarps with sensors detecting shortwave infrared (SWIR) wavelengths since the behavior was less predictable. Also, the chemical treatment used to induce constant emissivity properties affected the directional/directional reflectance of the tarp and resulted in a unique calibration equation.

FUTURE PLANS: We have plans to repeat these goniometer measurements to ensure high precision and to include tarps that were measured initially with low sensor gains. After that set of measurements, we plan to investigate the degradation of the swatches with time by exposing all the swatches to measured amounts of solar radiation and repeating the goniometer experiment using these exposed swatches.

REFERENCES: Jackson, R.D., T.R. Clarke and M.S. Moran (1992) Bidirectional calibration results for 11 Spectralon and 16 $BaSO_4$ reference reflectance panels, Rem. Sens. Env. 40:231-239.

COOPERATORS: Dr. Maas, Western Integrated Cropping Systems Research, Shafter, CA; Dr. Humes, Hydrology Lab., Beltsville, MD; Dr. Everitt, Subtrop. Agric. Res. Lab, Weslaco, TX; Dr. Schiebe, Natl. Agric. Water Qual. Lab, Durant, OK; Dr. Slater, Univ. Ariz. Optical Science Center, Tucson, AZ, Mr. Clyde, TRACOR GIE, Provo, UT.

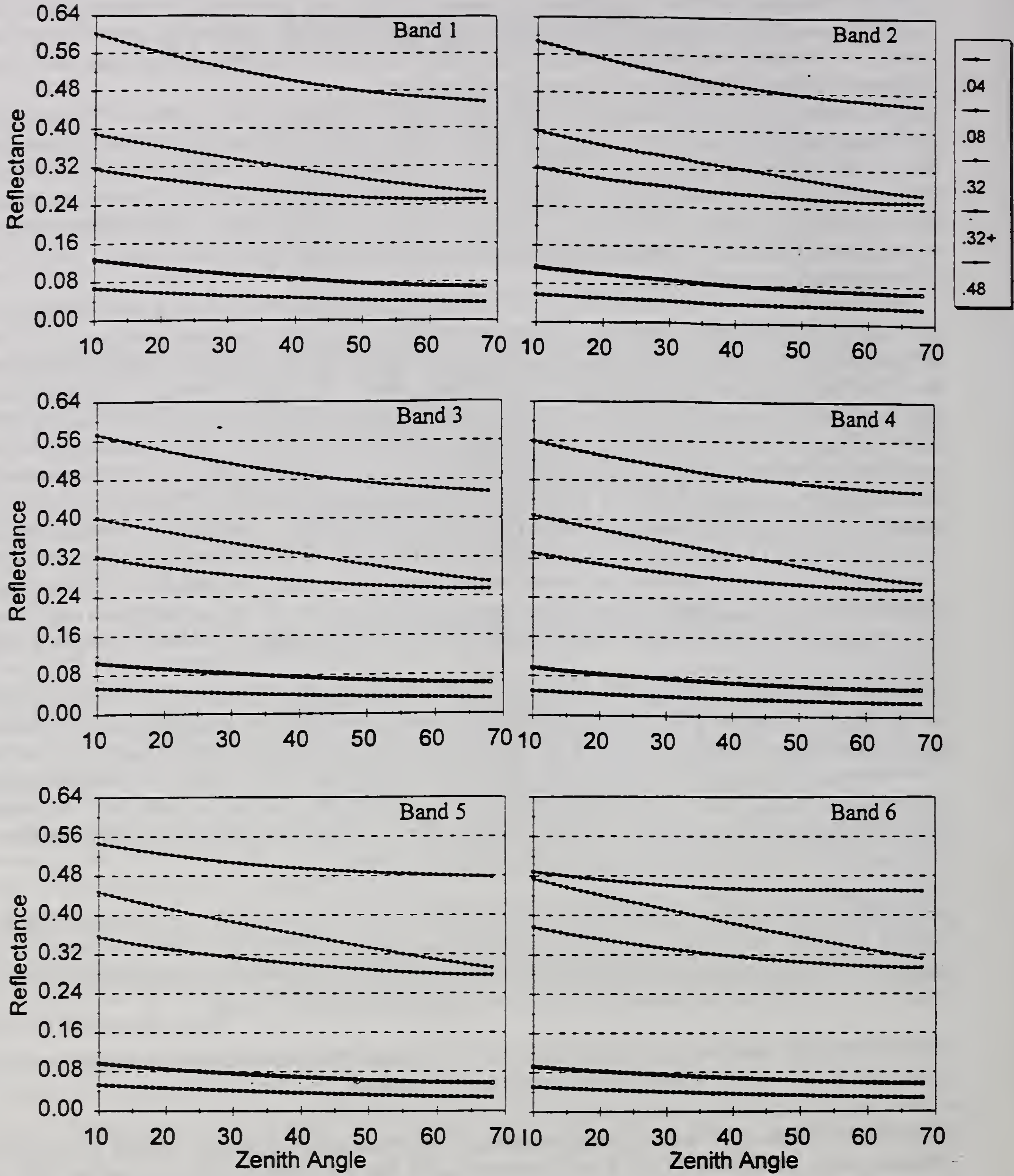

Figure 1. Reflectance factor values illustrated by spectral band (b1-b6) for swaths of different ρ(θ/h) values (listed in legends.

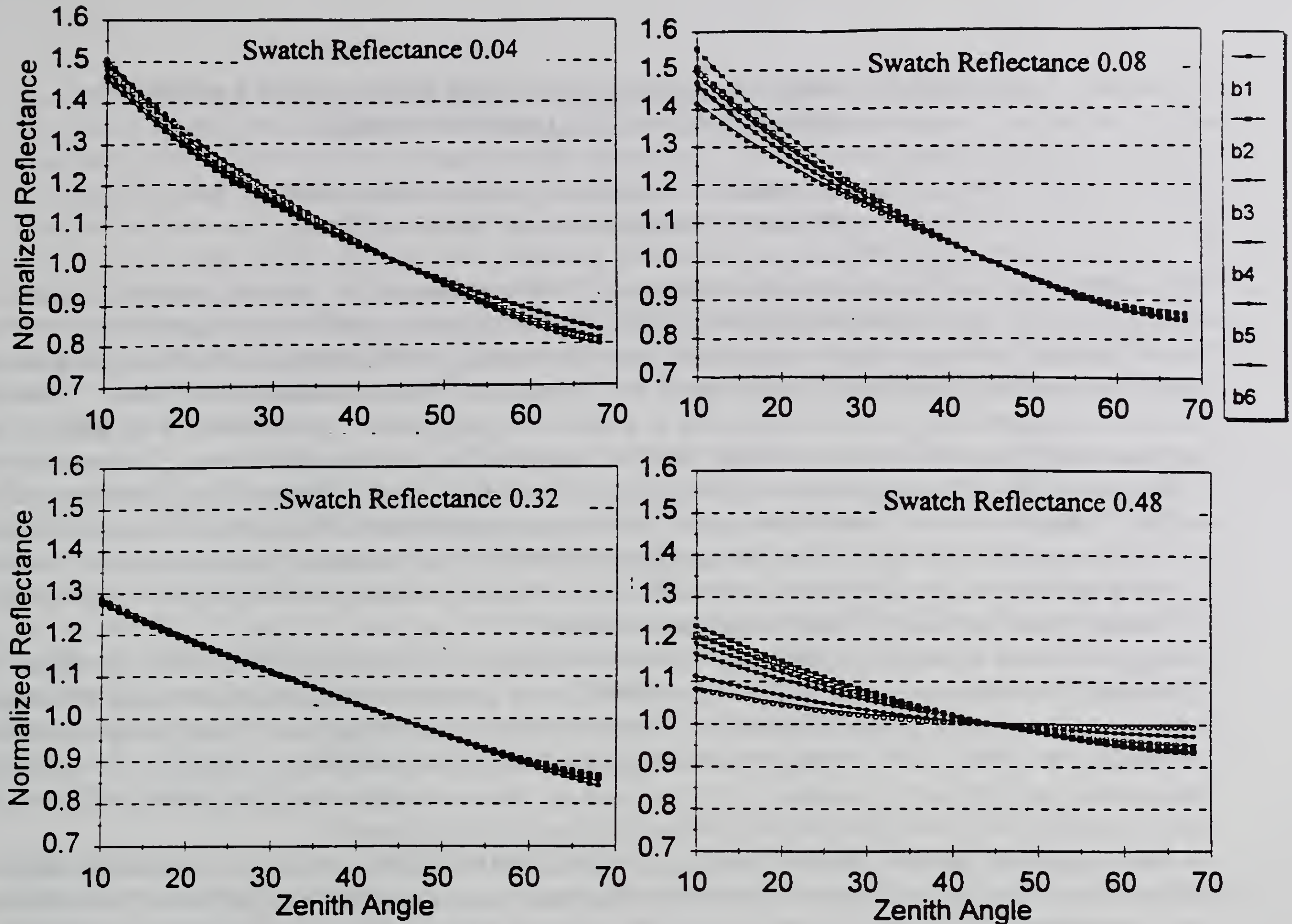

Figure 2. Reflectance factors for selected swatches and spectral bands b1-b6, normalized to a value of 1 at 45° to emphasize the differences in the shapes of the reflectance-zenith angle relationships.

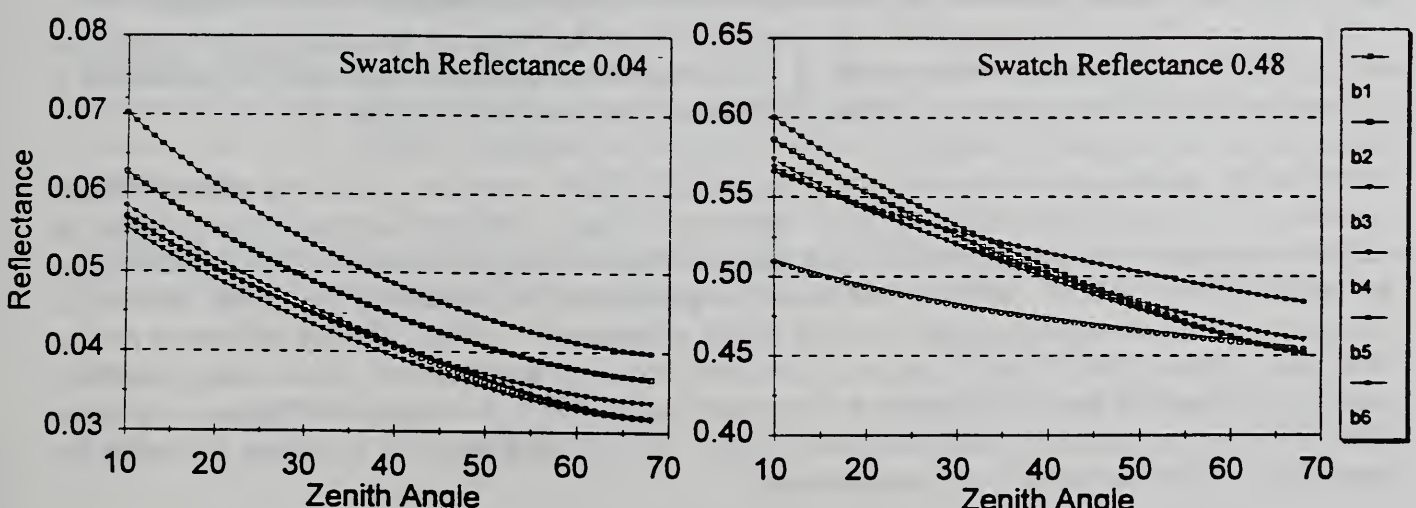

Figure 3. The general equations for tarps of $\rho(\theta/h)$=0.04 and 0.48, derived from the average of data for several swatches, with r^2 values greater than 0.99 for all bands (including b7) in both cases.

MEASURING GREEN LEAF AREA OF WHEAT USING THE LAI 2000 AND MULTISPECTRAL REFLECTANCE

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PROBLEM: Accurate estimation of green leaf index (GLAI) is a fundamental parameter in most agricultural field experiments. It is a dimensionless number, commonly defined as the surface area of green leaves present on all the plants growing in a given unit area (m^2/m^2). In practice, is it usually measured by sampling all the plants in a known area and separating the green leaves from the other plant components by hand. Then the leaves are measured using an optical planimeter or a video imaging system. Alternatively, if the specific leaf weights are known, GLAI can be inferred from the weight of leaves after oven drying. Obviously, these methods require very tedious, labor intensive, and time-consuming effort. They are also destructive and do not lend themselves to use in small plot studies where plant numbers are limited, nor are they useful where later measurements might be desired on the same plants. Establishing a reasonable threshold value for whether a leaf is green or not is also an arbitrary decision that introduces uncertain variation when experimental treatments induce chlorosis or early senescence of tissues.

Because of these limitations, considerable effort has focused on developing nondestructive approaches for estimating GLAI. Remote sensing studies at the USWCL have shown that observations of canopy reflectance from ground-, aircraft-, and satellite-based sensors represent a viable approach. Statistically significant correlations are present between multispectral vegetation indices (VIs) and GLAI. However, the empirical studies show that VIs tend to saturate at GLAI > 3 or 4 and the relationships for annual plants such as wheat are often different before and after the date when maximum GLAI is attained.

Another approach uses the LAI-2000 Plant Canopy Analyzer (LI-COR, Inc., Lincoln, Nebraska) to estimate plant area index (PAI). PAI is used in this sense to indicate the area of all plant parts (leaves, stems, heads, etc., regardless of whether they are green or not). The fish-eye optics of the LAI-2000 projects a hemispheric image onto five silicon detectors arranged in concentric rings such that each detector sees a different portion of the sky. Measurements are taken above and below the plant canopy. A built-in, radiative transfer model is then used to estimate PAI from the interception of light by foliage in each of the five different angles. Empirical studies show good correlation between LAI-2000 data and PAI derived by conventional destructive measurements. The LAI-2000, however, is essentially unable to distinguish between green and nongreen canopy elements, diminishing it's utility in canopies where nonphotosynthesizing tissues are present.

The objective of this study was to develop a more precise methodology for determining green plant area index (GPAI) throughout the entire season by combining the green-pigment-detecting capabilities of a radiometrically acquired multispectral VI and the PAI measured with the LAI-2000.

APPROACH: Experiments were conducted during the FACE 93-94 experiment with spring wheat (*Triticum aestivum*, L. cv Yecora Rojo) at the Maricopa Agricultural Center. Experimental treatments consisted of ambient and elevated (550 μmol μmol^{-1}) CO_2 concentrations and two irrigation regimes (Wet, ~consumptive demand; Dry, 50% of Wet). GPAI (green leaves plus green stems) was measured at 7-10 day intervals by conventional destructive sampling and use of an optical planimeter (LI-3000). Canopy reflectance factors (Red, 0.61-0.68 μm; NIR, 0.79-0.89 μm) were measured frequently throughout the season using a handheld radiometer at a morning time corresponding to a solar zenith angle of 57°. A normalized difference vegetation index (NDVI) was computed as (Red-NIR)/(Red+NIR). The LAI-2000 was used to estimate PAI using the manufacturer's built-in radiative transfer algorithm.

FINDINGS: Seasonal trajectories of observed GPAI (n=20 dates) and estimated PAI (n=12 dates) are shown for plants in the two irrigation treatments exposed to ambient (fig. 1) and FACE CO_2 levels (fig. 2). Trends reveal that the LAI-2000 estimates GPAI reasonably well early in the season but underestimates it by about 1 unit during mid-season for the Wet irrigation treatment. Towards the end of the season, however, when leaf

senescence begins to occur, the LAI-2000 seriously overestimates GPAI. This quantitative relationship is portrayed in figure 3, where GPAI are shown as a function of LAI-2000 PAI estimates. All the data for both irrigation and CO_2 treatments are included in this scatterplot. The fitted regression is close to the expected 1:1 relationship, but this is due to the presence of outliers that were taken in the final weeks of the experiment when senescence was increasing. Overall, the standard error of the estimates from this predictive equation is about 1 unit PAI, about twice the error normally obtained in conventional observations of GPAI. The residuals from the equation of figure 3 are plotted against fractional greenness (FG) of the canopy in figure 4, where FG was computed as the ratio of green to total leaf biomass on a dry weight basis. This residual analysis shows the importance of FG in PAI measurements. Midway into senescence, when the canopy is 50% green, the LAI-2000 overestimates GPAI by more than 1 unit; when only 20% of the canopy is green, the overestimate is over 2 units.

Because of its sensitivity to canopy greenness, the NDVI offerred an attractive, independent means for improving the performance of the LAI-2000. First, multiple regression was used to develop a predictive relationship for FG using NDVI and canopy height observations as independent variables. Canopy height was included as a surrogate parameter for crop phenology that corrected the late-season hysteresis in NDVI referred to above and enabled well-behaved prediction of FG from the beginning to the end of the season. In fact, for the entire range of this data set, NDVI and height accounted for 95% of the variability in predicting FG (fig. 5). Then this estimate of FG (constrained so as not to exceed 1) was used as a second independent variable in a multiple regression approach for refining the GPAI predictive capabilities of the LAI-2000. Results (fig. 6) show a significant improvement over the original relationship (fig. 2). The new model accounts for 95% of the variability in GLAI and improves the standard error of the estimate to a tolerable 0.5 units GPAI throughout the season.

INTERPRETATION: The LAI-2000 is equipped with a filter that rejects radiation above 0.49 μm. As a result, photosynthetically active plant tissues appear black to the sensor and contrast sharply with the bright diffuse sky radiation. When canopy elements become chlorotic or senesce, they appear less black to the sensor but still much darker than the sky. Thus, one would expect the LAI-2000 readings to decline slightly as was shown by the plants in the Dry irrigation treatment of figures 1 and 2. However, the readings do not follow the expected end-of-season decline in GPAI, and serious errors occurred in PAI estimates during senescence. It is suspected that chlorosis resulting from disease or nutrient deficiencies would cause similar errors. Use of a multispectral VI such as the NDVI with the LAI-2000 can compensate for these problems and provide accurate, noninvasive estimates of GPAI in studies where nonphotosynthesizing green tissues are present.

FUTURE PLANS: The LAI-2000 was used in the FACE 95-96 experiment in which Yecora Rojo wheat was exposed to two levels of soil nitrogen and two levels of CO_2. This data set is currently under analysis to test whether this new combined technique for estimating GPAI is rigorous enough to account for nitrogen deficiencies.

COOPERATORS: The authors wish to acknowledge the support offered by the Potsdam Institute for Climate Research and the generous loan of a Plant Canopy Analyzer from LI-COR, Inc., for the 1995-96 season.

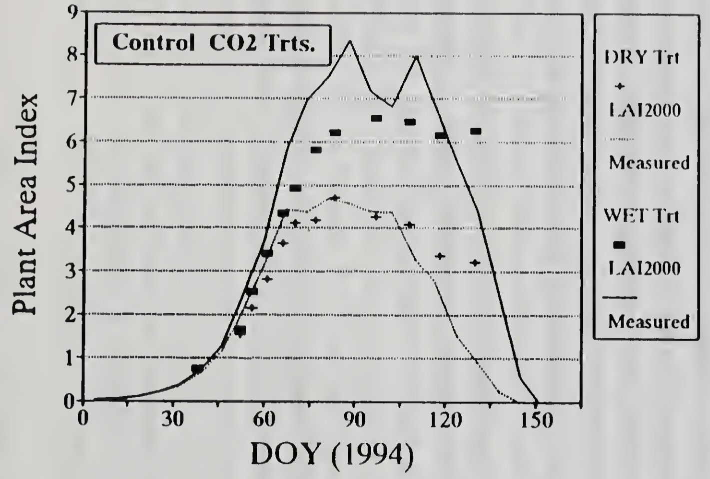

Figure 1. Measured green plant area index (GPAI, lines) and LAI-2000 plant area index observations (PAI, data points) obtained in the CONTROL treatments during the FACE 1993-94 Wheat experiment.

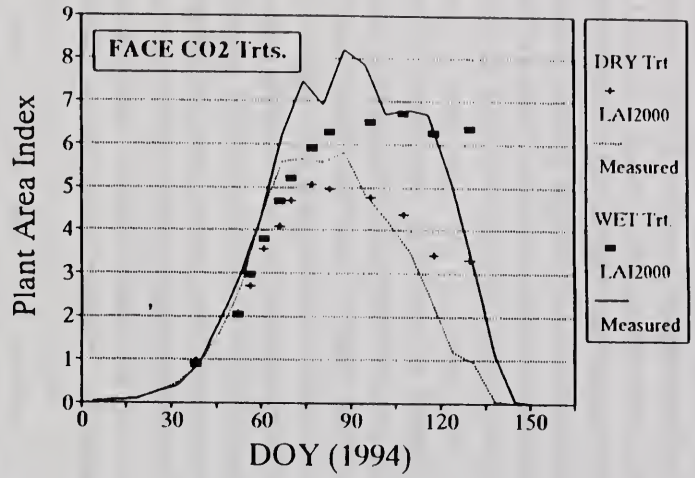

Figure 2. Measured green plant area index (GPAI, lines) and LAI-2000 plant area index observations (PAI, data points) obtained in the CO2 treatments during the FACE 1993-94 Wheat experiment.

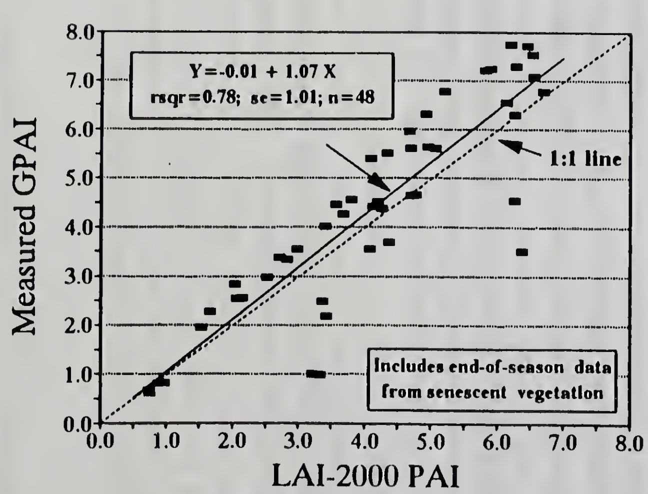

Figure 3. Measured values of green plant area index (GPAI, sum of green leaves and stems) versus the LAI-2000 estimate of plant area index (PAI).

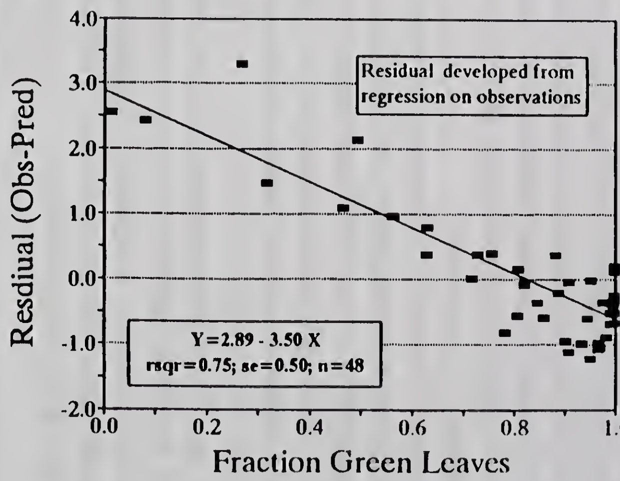

Figure 4. Residuals from regression in fig 3 (Observed - Predicted) versus the fraction green parameter (FG) defined in the text.

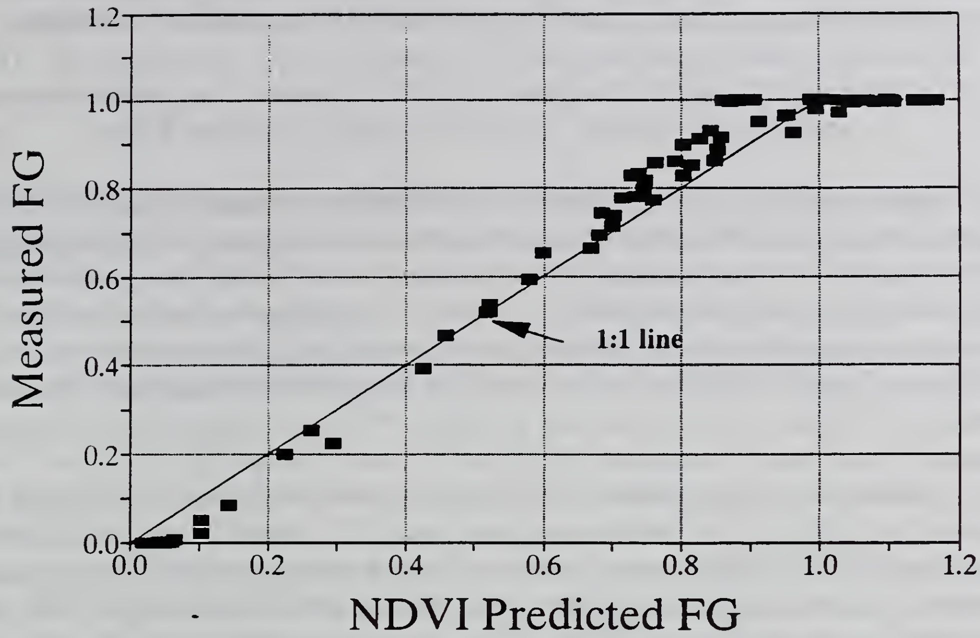

Figure 5. Measured fraction green (FG, ratio of green to total leaf biomass) versus the NDVI-based prediction of FG described in the text.

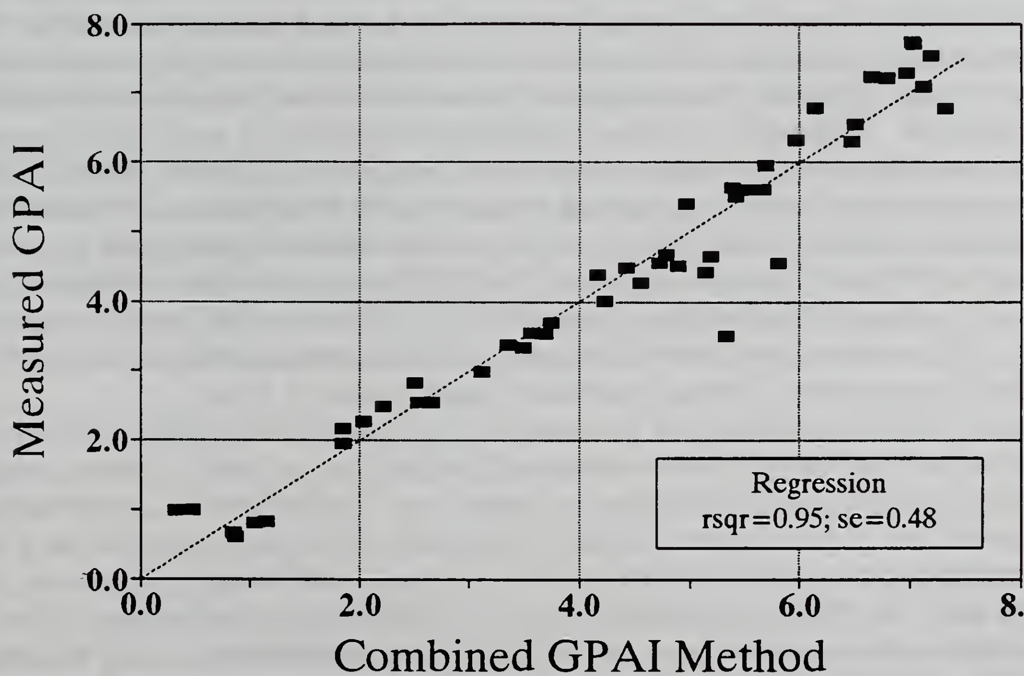

Figure 6. Measured GPAI versus Predicted GPAI based on new approach that combines native LAI-2000 PAI estimates and NDVI predicted FG parameters.

EFFECTS OF ELEVATED CO_2 AND SOIL NITROGEN ON ABSORPTANCE OF VISIBLE AND NEAR-INFRARED LIGHT BY WHEAT LEAVES.

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and S. M. Gerszewski, Biological Science Technician Plants

PROBLEM: Temporal changes in the reflectance, transmittance, and absorptance characteristics of wheat leaves exposed to Free-Air Carbon dioxide Enrichment (FACE) and reduced soil nitrogen supplies have not been adequately studied. Such information is needed to better understand the capture of light for use in photosynthetic pathways, for accurate modeling of radiative transfer in the canopy, and for determining the utility of remote sensing techniques in monitoring and quantifying plant response to an ever-changing environment. This study was undertaken to provide a high resolution spectral data set that will help achieve these objectives.

APPROACH: Measurements were obtained within the experimental framework provided by the 1995-96 FACE wheat experiment which is described in more detail in the U.S. Water Conservation Laboratory Annual Research Report for 1996 by Kimball et al. and Pinter et al. Briefly, the experimental design included two levels of atmospheric CO_2 (herein referred to as Blower, ~360 and FACE, ambient plus 200 μmol mol^{-1} CO_2) and two levels of soil nitrogen (High N, 350 kg N ha^{-1}, and Low N, 70 kg N ha^{-1}). CO_2 enrichment was started shortly after plant emergence and continued 24 hours a day until the plants were mostly senescent and ready to be harvested. Adequate moisture was provided to the plants throughout the season via a subsurface microirrigation (drip) system.

Beginning on February 22, 1996, and continuing until May 18, 1996, hyperspectral measurements were made on leaves at approximately weekly intervals. One representative plant from each replicated field plot was selected from each treatment combinations. Plants were transported to the field trailer for measurement in an insulated, cool chest. Leaves were detached from the plant and measured within 20 minutes of field sampling. Measurements were made on the uppermost leaf of the main stem until March 20, 1996. After that, data were obtained on each of the top three leaves. Reflectance and transmittance measurements were made at two spots within the middle third of each leaf blade. Both adaxial (upper) and abaxial (lower) leaf surfaces were measured. Absorptance was then calculated as a residual in a simple light balance equation. When heads appeared above the ligule, they were also included in the measurement routine.

The spectroradiometer that we used was a Personal Spectrometer II (PSII) produced by Analytical Spectral Devices, Inc., Boulder, Colorado. It was used in conjunction with an external integrating sphere (LAI-1800) manufactured by LI-COR, Inc., Lincoln, Nebraska. The PSII has a nominal 350- to 1050-nm response. It collects light via a bundle of 19 optical fibers, transports it to a 100 mm focal length, holographic grating where the light is diffracted into respective wavelengths and distributed across the surface of a 512 element, silicon photo diode array detector. Spectral resolution is approximately 1.4 nm.

The procedure we followed in making the measurements was designed to minimize sources of bias in the resulting spectra that were not related to the interaction of light with the leaf itself. Reference measurements of the pressed $BaSO_4$ powder used in the integrating sphere were obtained with the appropriate leaf surface blocking the sample port. An equation describing reflectance of the $BaSO_4$ standard as a function of wavelength was developed from technical literature (The Eastman Kodak Company, Rochester, New York) and applied to the data. The PSII dark subtraction routine was implemented at frequent intervals and whenever the instrument integration times were changed. An additional set of measurements, which we called the dark sphere corrections, were made with the lamp from the integrating sphere aimed through an empty sample port. This established the amount of stray lamp light that was not completely collimated, and thus, was bouncing around the sphere and needed to be subtracted from reflectance measurements. A separate test established multipliers that were used with specific integration times.

A handheld chlorophyll meter, SPAD 502 (Minolta, Corp.) was also used to obtain an average reading in the same area on the leaf where the spectroradiometric measurements were taken. Leaf discs were extracted using 80% acetone for determinations of chlorophyll a and b and accessory pigments (carotenoids and xanthophylls). The remainder of the leaf blade was dried and ground using a standard no. 20 mesh screen. Subsamples were subjected to carbon and nitrogen analyses in a gas chromatograph (Eager 200, C & E Instruments).

FINDINGS AND PRELIMINARY INTERPRETATION: Reduction and analysis of this large data set have only just recently begun. The hyperspectral data obtained with the PSII and the integrating sphere that we show here are for the adaxial surface of the uppermost leaf on just two dates. The first, on March 20, 1996, was about 1 week before head emergence; the second, April 24-25, 1996, during early-to-mid grain fill. Data are averages from 4 replicates of each treatment. They show a systematic decline in absorptance in the visible wavelengths that is associated with the Low N treatment as early as Mar 20 (figs. 1a and 1b). Interestingly, the absorptance of visible light was 2-3% higher in the elevated CO_2, High N leaves. By late April, absorptance of visible light is slightly greater in the high N treatments. In the Low N leaves, however, it is dramatically reduced, and a large difference had developed between Blower and FACE treatments, Low N treatments.

Flag leaf nitrogen contents also revealed large differences between High and Low N treatments on April 24-25, 1996 (fig. 3.). They also revealed that the N content of flag leaves sampled in the Ambient plots (ambient CO_2, without blowers) was higher than in their Blower counterparts, suggesting the possibility that these plants in that part of the field had better access to soil nutrients and/or more favorable growing conditions than the plants in Blower and FACE arrays. PAR absorptance was computed as the mean absorptance over the wavelengths from 400 to 700 nm. Treatment averages are shown in figure 4. Once again, the nitrogen effect is most conspicuous. However, there was essentially no difference between flag leaf PAR absorptance of Ambient High and Low N, nor between Blower High N and FACE High N treatments.

We found strong correlations between the percent nitrogen concentration in the flag leaves on April 24-25(fig. 5.) and average absorptance of light in the photosynthetically active portion of the spectrum (PAR, 400-700 nm). Unfortunately, at the higher N contents, a relatively large change in leaf N elicits a small change in PAR absorptance. Similar correlations were found between N content and the SPAD readings, suggesting a physical basis for use of the latter instrument in assessing pigment status (fig. 6).

FUTURE PLANS: Analysis and reduction of the data set will continue. We are interested in the spectral changes that which occur in lower leaves and heads as the canopy begins senescence. An important question focuses on whether nitrogen concentrations and pigment levels become decoupled towards the end of the season. Comparisons between single leaf and canopy-level hyperspectral data will also reveal whether fine spectral details associated with nutrient status and CO_2 levels can be detected on a canopy basis. Future plans include measurements of a similar nature during the 1996-97 FACE experiment.

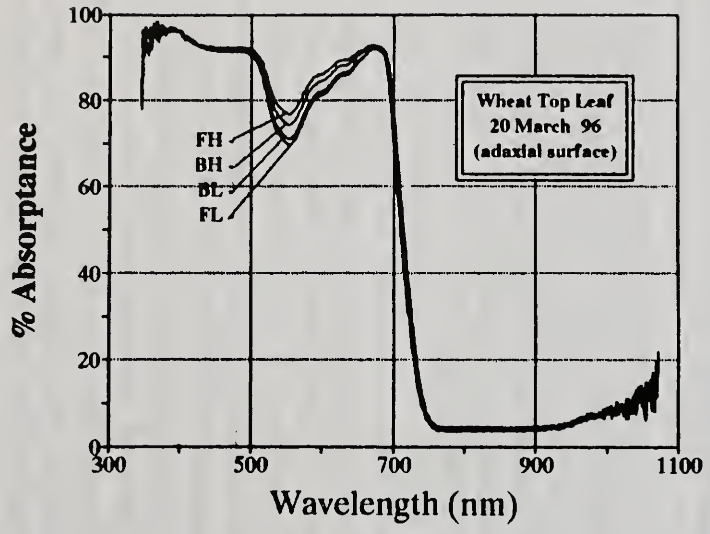

Figure 1a. Absorptance measured on spring wheat in the FACE Experiment on 20 March 96 (DOY080). Data are from the adaxial surface of the uppermost mainstem leaf and represent averages from 4 replicates per treatment.

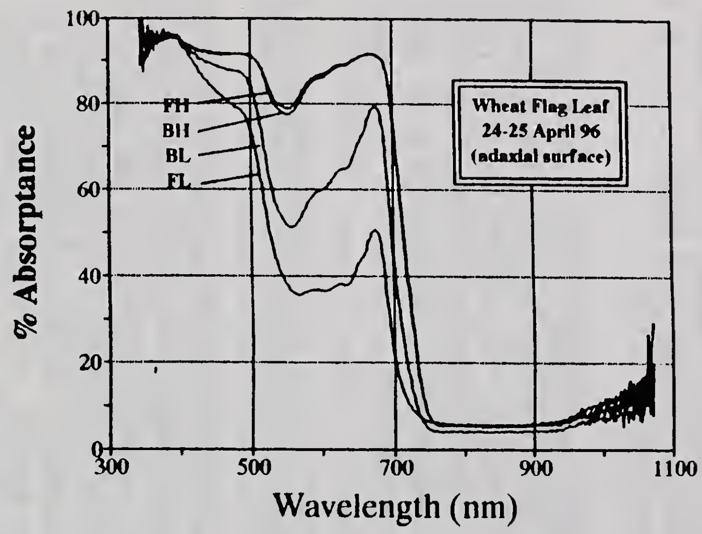

Figure 2a. Absorptance measured on spring wheat in the FACE Experiment on 24-25 April 96 (DOY114-115). Data are from the adaxial surface of the flag leaf on the mainstem and represent averages from 4 replicates per treatment.

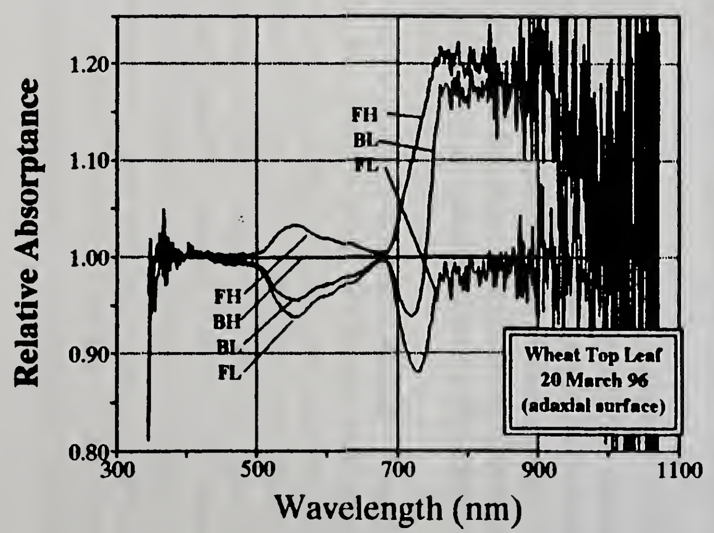

Figure 1b. Absorptance relative to that measured on leaves in the Blower High N treatment on 20 March 96 (DOY080). Data are from the adaxial surface of the uppermost mainstem leaf and represent averages from 4 replicates per treatment.

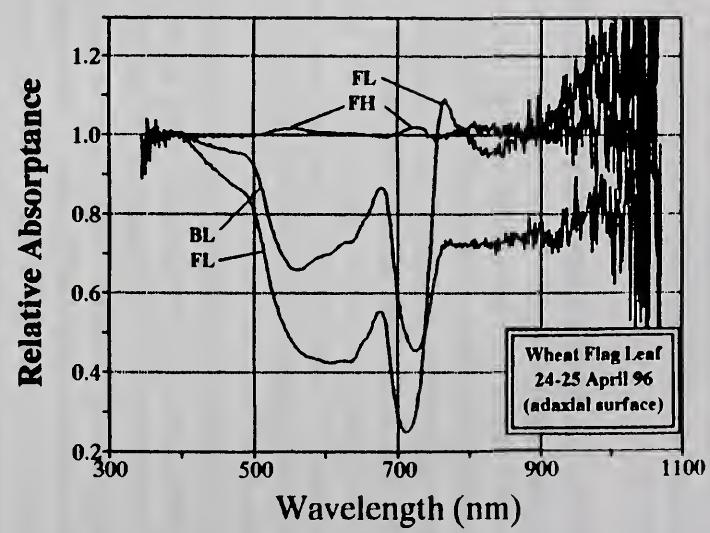

Figure 2b. Absorptance relative to that measured on leaves in the Blower High N treatment on 24-25 April 96 (DOY114-115). Data are from the adaxial surface of flag leaf on mainstem and represent averages from 4 replicates per treatment.

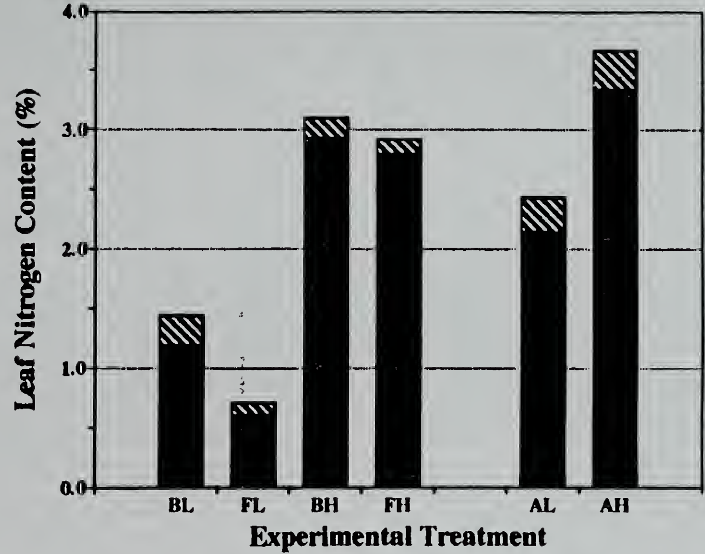

Figure 3. Flag leaf nitrogen concentrations on 24-25 April 1996. Abbreviations: BL=Blower Low N; BH=Blower High N; FL=FACE Low N; FH=FACE High N; AL=Ambient Low N; AH=Ambient High N. Bars show means + std err of 4 reps.

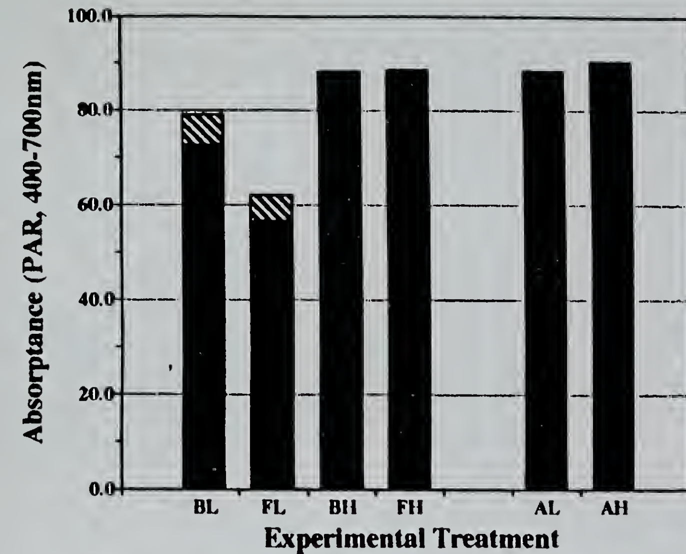

Figure 4. Average PAR (400-700 nm) absorptance of adaxial surface of Flag leaf on 24-25 April 96. Abbreviations are same as in fig. 3. Bars show mean plus one standard error of measurements in 4 replicates.

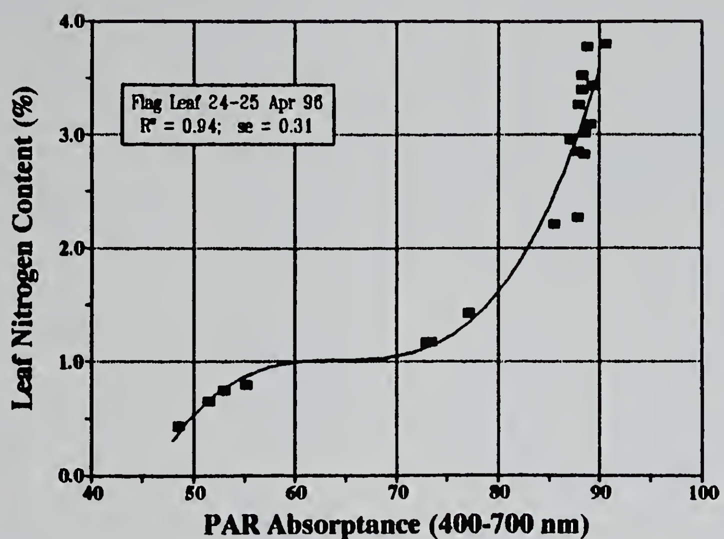

Figure 5. Relationship between flag leaf N concentration and PAR absorptance on 24-25 April 96.

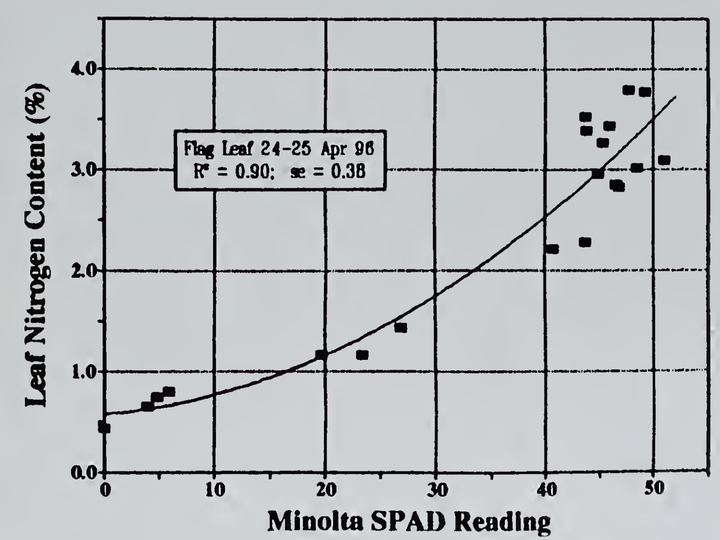

Figure 6. Relationship between flag leaf N concentration and SPAD readings on 24-25 April 96.

FARM MANAGEMENT DECISIONS USING A REMOTE SENSING AND MODELING APPROACH

VALIDATION OF MODELED PLANT AND SOIL SURFACE TEMPERATURES

T. R. Clarke, Physical Scientist; M. S. Moran, Physical Scientist; and D. J. Hunsaker, Agricultural Engineer

PROBLEM: In arid environments, high daytime temperatures coupled with low humidity result in a large amount of water being evaporated from the soil surface and transpired through the leaves of crops (and weeds). The transition from no stress to an economically harmful level of water stress can occur quite rapidly, making irrigation timing a major concern of growers.

Hand-held infrared thermometers (IRTs) have been shown to be effective tools in detecting water stress in crops. These devices are radiometers sensitive to thermal electromagnetic radiation in the 8 to 12 micron band, which can be converted to surface temperature for targets (such as vegetation) having a high emissivity. As the water supply in the root zone becomes depleted, transpiration is reduced, solar energy normally absorbed through evaporation within the leaves is converted to heat, and the leaf temperature increases relative to air temperature. The method is particularly effective in hot, arid environments where the leaf temperature of a well-watered plant can be more than ten degrees Celsius cooler than the air when the relative humidity is very low.

A major difficulty in applying infrared thermometry to irrigation management is that nadir-looking instruments cannot be used if exposed soil is within the sensor's field of view. A dry, bare soil can have a midday temperature that is more than twenty degrees Celsius above air temperature and thirty degrees higher than a nonstressed canopy temperature. One can easily see how even a small percentage of exposed soil in the field-of- view of an infrared thermometer can produce an erroneously high composite temperature, leading to premature irrigation. The problem has been circumvented by carefully angling hand-held IRTs to exclude bare soils, but airborne or satellite-based monitoring was feasible under only near-full canopy cover conditions. A means of compensating for various amounts of exposed bare soil was developed to allow the method to be used throughout the growing season. The method, termed the VIT trapezoid, was based on energy balance equations previously developed for complete canopies and modifying them for use in predicting temperatures of very wet and very dry bare soils. Using these four predicted surface-minus-air temperatures (fully transpiring full cover, nontranspiring full cover, freely evaporating wet,bare soil, and completely dry, bare soil) as vertices, a typically trapezoidal polygon having percent vegetative cover (estimated using a Vegetation Index) as the ordinate and surface-minus-air temperature as the abscissa can be constructed for a particular meteorology and crop type (Moran et. al., 1994). Every unit of ground area within the field can be mapped within this trapezoid, and from its position, information such as relative evapotranspiration and water-related crop stress can be determined. Before the method can be applied for farm management, the validity of the trapezoid vertex calculations must be verified. In particular, the calculation for dry, bare soil had not been tested for reliability with field measurements.

APPROACH: As part of a comprehensive field experiment held at the Maricopa Agricultural Center during the 1996 cotton season, multispectral measurements using yoke-mounted optical and thermal infrared radiometers were made on fixed transects through cotton plots having various irrigation treatments that provided a range of plant water and growth statuses. During measurements, it was often possible to find targets representative of trapezoid vertices; a bare soil target was always included, while wet soil, well-watered cotton canopy, and highly stressed cotton canopies were measured when such targets presented themselves. The observed temperatures were then compared to those predicted by the energy balance equation, using meteorological data from an AZMET station located a few hundred meters from the plots. Eight sets of yoke data were collected as of August 31. Trapezoid vertices were calculated for seven of these dates, six of which are shown in figure 1. Calculated vertices are shown as gray circles, and observed values, when available, as gray rectangles.

FINDINGS: Agreement between observed and calculated values was good for three of the vertices, given that the completely unstressed and completely water-stressed plant canopy conditions were probably never

actually observed. However, predicted surface temperatures for the dry, bare soil vertex varied widely from those observed, with errors of up to 16°C. Analysis of the meteorological data revealed an inverse relationship between the magnitude of the error in predicted temperature and recorded wind speed, as seen in figure 2. The one data point that did not follow the trend of increasing error below wind speeds of 1.6 m/sec was collected on a day of intermittent cloud interference with the sun during the time of measurement, affecting the incoming solar component of the calculation as well as the observed temperature. As the soil temperature does not rebound instantly from shading as the calculation allows, this datum was excluded from analysis.

INTERPRETATION: There is clearly a factor in the thermal dynamics of a bare, dry soil surface that dominates at very low wind speeds and for which improper compensation is being made. At this time, we are not certain if the phenomenon is caused by unaccounted convective heat loss or by a poor estimate of roughness length, one of the inputs for the aerodynamic resistance component of the calculation. The error appears predictable, however, which will allow stochastic corrections to be made until the physics are better understood. Since the approach used was opportunistic, not enough bare surface temperatures were collected to define clearly the error function, which must be done.

FUTURE PLANS: A dedicated set of bare soil temperature and wind speed data will be collected. The energy balance equations will be run and compared with the large observed data set to develop a more precise error function equation. The model will then be run with various roughness lengths to see if the error can be reduced. Finally, a convective heat loss component based on flat plate convection formulae will be introduced if necessary to further reduce the predictive error.

COOPERATORS:
The University of Arizona Maricopa Agricultural Center and Steve Husman of the Maricopa County Cooperative Extension Service.

REFERENCE:
Moran, M.S., T.R. Clarke, Y. Inoue, and A. Vidal. 1994. Estimating crop water deficit using the relation between surface-air temperature and spectral vegetation index. Remote Sens. of the Environ. 46:246-263.

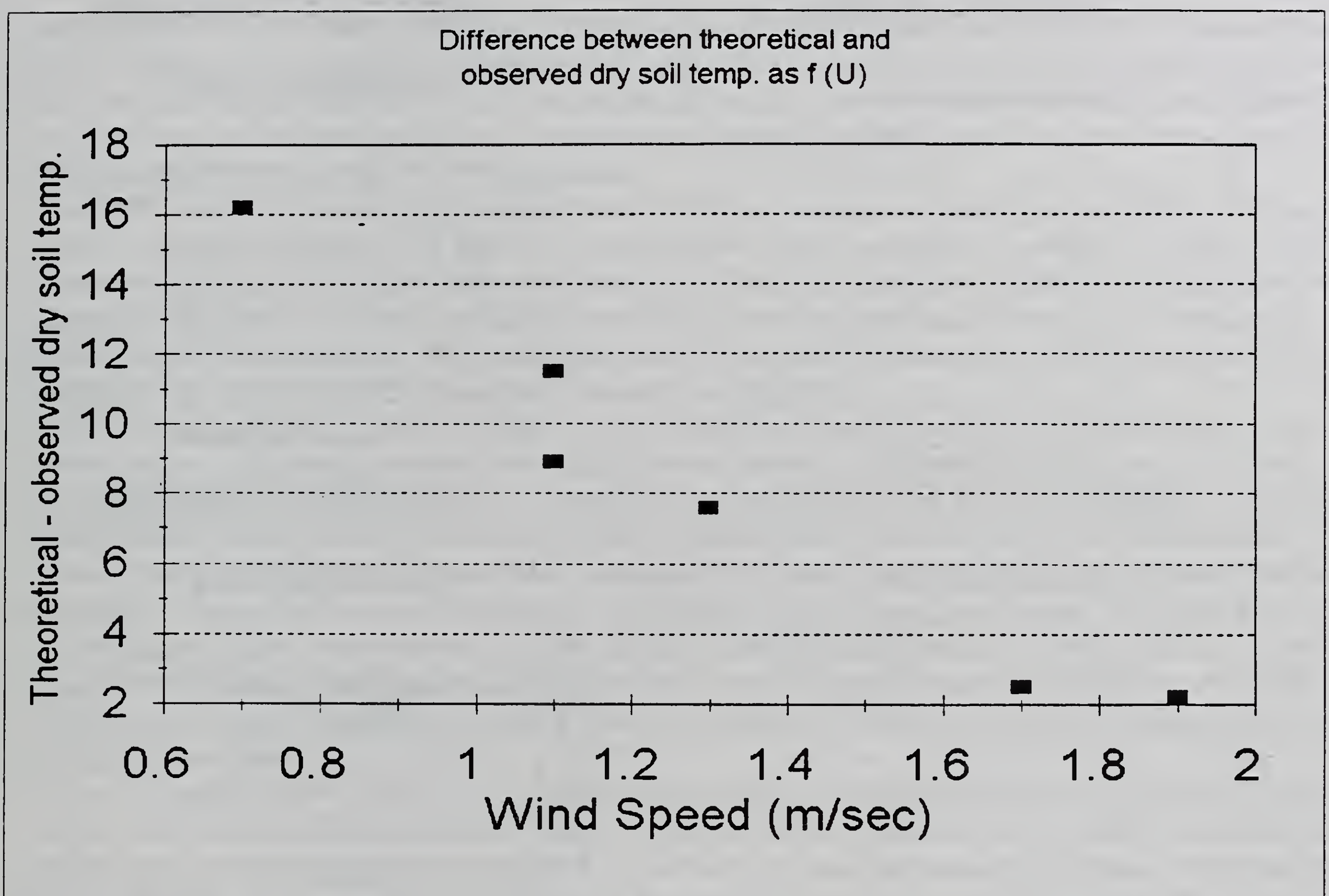

Figure 2. ~~Difference between~~ calculated and observed dry soil temperatures as a function of wind speed at screen height.

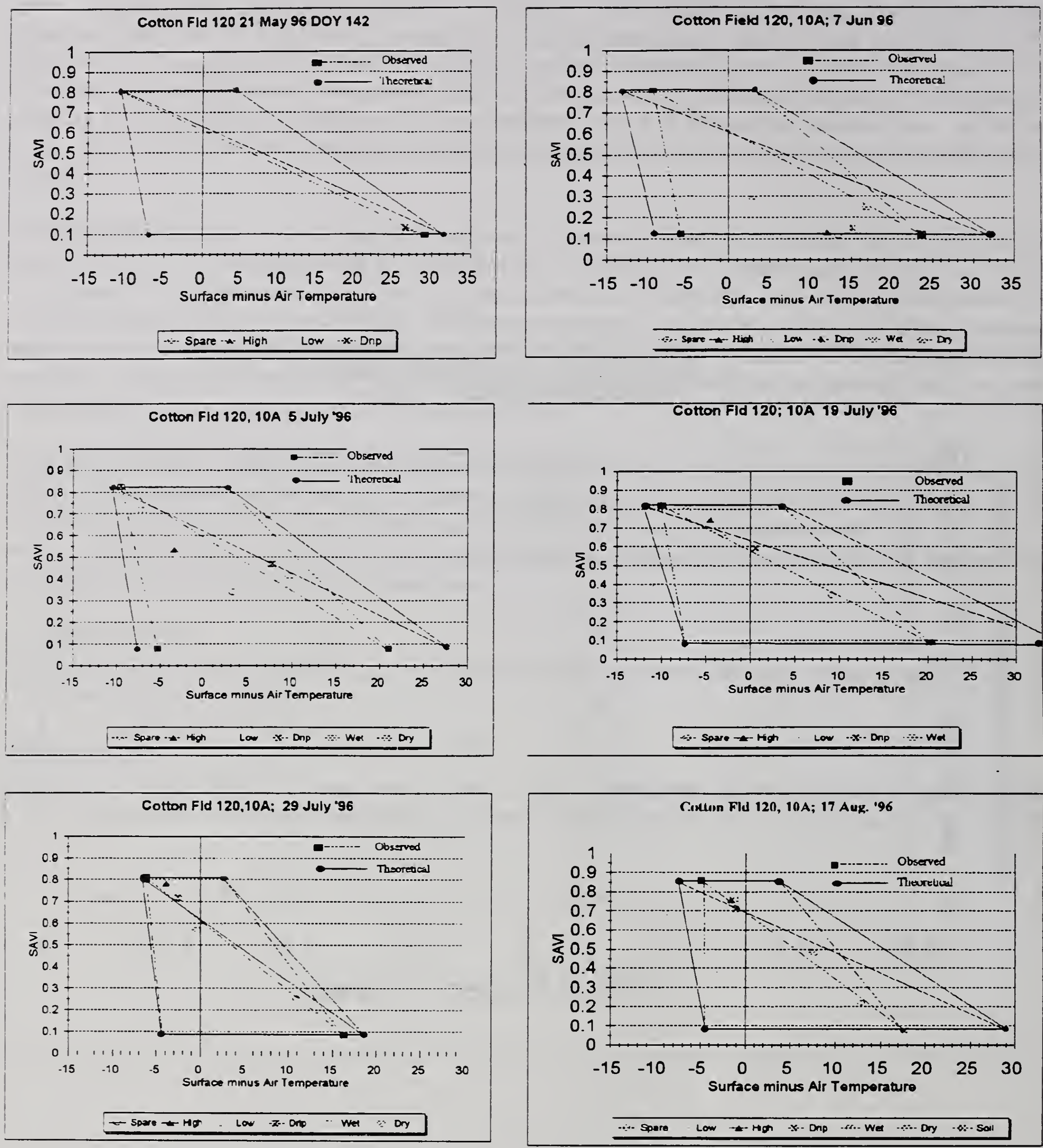

Figure 1. Calculated and observed VIT trapezoids for six clear days during the '96 cotton season. Note the wide variance at the dry, bare soil (lower right) vertex. Average VIT values for the six irrigation treatments are also shown.

A MODELING/REMOTE SENSING APPROACH FOR SCHEDULING COTTON IRRIGATIONS

M. S. Moran, T. R. Clarke, Physical Scientists,
P. J. Pinter, Jr., Research Biologist, J. Qi, Physical Scientist, B. A. Kimball, Supervisory Soil Scientist

PROBLEM: Each year, farm managers in arid/semi-arid regions face the difficult task of determining the timing of crop irrigations and the optimum amount of water to be applied. Such decisions are often based solely on meteorological conditions such as air temperature and solar irradiance, without regard for actual crop and soil conditions. An alternative may be to combine such information from meteorological stations with images of crop conditions acquired with sensors aboard low-flying aircraft. A method is proposed to use a physical model with readily-available meteorological data and periodic updates from airborne images to produce accurate, daily estimates of crop evaporative water loss and crop growth.

APPROACH: The PROtotype Biomass and Evaporation (PROBE) model (developed by Dr. Stephan Maas at ARS, Shafter, Ca.) was used to simulate crop evaporation rates and predict biomass and leaf production based on basic meteorological data and physical models of crop growth and soil water depletion (Figure 1). The model was automatically updated with remotely-sensed measurements of actual crop evaporation rates (E) and green leaf area index (GLAI), when available.

The within-season calibration procedure allows PROBE to incorporate remotely-sensed data and improve overall simulation accuracy. The iterative, numerical procedure manipulates five initial conditions and/or parameters (initial GLAI, initial soil water content, soil field capacity, leaf partitioning fraction, and leaf lifespan) so that they converge on values that result in the model simulation of E and GLAI fitting the set of remotely-sensed measurements. This calibration procedure is totally automated and simply requires periodic measurements of GLAI and E derived from remotely-sensed inputs.

The study reported here is a test of PROBE for monitoring crop evaporative water loss over an entire cotton growing season. This study was part of the Multispectral Airborne Demonstration at Maricopa Agricultural Center (MADMAC) conducted at MAC, located 48 km south of Phoenix, Arizona. Starting in April 1994 (near the time of cotton planting) and ending in late September 1994 (near the time of cotton defoliation), we obtained multispectral video images of MAC at regular (1-2 week) intervals. A total of fourteen cloudfree images were obtained with green (0.50 μm), red (0.65 μm), NIR (0.85 μm) and thermal (8-12 μm) filters (at 2-m ground resolution) at approximately 1100-1200h each day. Remote estimates of GLAI ($GLAI_{RS}$) and E (E_{RS}) were derived for each field and border from the spectral images as described by Moran et al. (1996). These estimates were validated with ground-based measurements made by a team of scientists during each MADMAC overpass.

Near the center of MAC, there was an Arizona Meteorological (AZMET) station which provided hourly values of solar radiation (R_{si}), wind speed (U), air temperature (T_a), and vapor pressure (VP) throughout the year. This station also provided an estimate of open water or pan evaporation (E_p) based on the modified Penman equation. Instrumentation was installed in the center of a 1.5 ha cotton field (Field #116, border #5) to measure hourly values of net radiation (R_n), soil heat flux (G) and actual evaporation rate (E_{BR}, based on the Bowen ratio method) throughout the growing season. Field #116, border #5 (hereon referred to as F116-5) experienced severe leaf perforator damage at an early date (DOY 235), and consequently, the cotton crop died near DOY 250.

FINDINGS: The PROBE model was run for the cotton in F116-5 for the time period prior to severe leaf-perforator infestation (DOYs 120-230, Flights 2-11). Model simulated values of GLAI corresponded well with the remotely-sensed GLAI inputs (Figure 2a). This correspondence illustrated the ability of the PROBE within-season calibration procedure to refine model parameters to produce a GLAI simulation ($GLAI_m$) in good agreement with $GLAI_{RS}$. Model simulated values of E (E_m) showed a good correspondence with the five remotely-sensed E inputs (E_{RS}), within the constraints of the meteorological input and the model initial

conditions and parameters (Figure 2b). E_m appeared particularly sensitive to irrigation dates, resulting in peaks and valleys associated with high and low soil water conditions.

We found that the areas of greatest discrepancy between E_m and E_{BR} were for periods of anomalous crop behavior (e.g., DOYs 203-213) when remotely-sensed data were unavailable (Figure 2b). There was an irrigation on DOY 210, and the E_{RS} inputs for DOYs 202 and 214 were both high (> 10 mm/day). Thus, E_m for this period remained between 10 and 14 mm/day. On the other hand, E_{BR} decreased steadily during this period to about 1 mm/day on DOY 209. Because we did not have a remotely-sensed estimate of E associated with this anomaly, it was not evident in the PROBE simulation and a large divergence between E_m and E_{BR} resulted.

For irrigation scheduling purposes, it is useful to compute the ratio of E_m to E_p and plot $(1-E_m/E_p)$ over time. Such a plot of two cotton fields (F116-5 and F107-4) gives a dramatic illustration of the well-watered and water-stressed periods over the season (Figure 3). The distinctive drop in $(1-E_m/E_p)$ for both fields from DOY 120 to 170 is associated with the increase in transpiration due to increases in GLAI. After DOY 170, when GLAI > 2.0, the peaks of $(1-E_m/E_p)$ are associated with decreases in transpiration due to dry soil conditions. Thus, it may be possible for the farm manager to obtain a daily graph of this type with the temporal history of each field and determine which fields need irrigation each day. Furthermore, the model could be run for several days beyond the current date (using predictions of meteorological conditions in the next 3-5 days) and provide the farm manager with a prediction of E and GLAI conditions in each field assuming no irrigation were provided.

INTERPRETATION: By combining the daily simulation of the PROBE model and the periodic updates of the remotely-sensed inputs, it was possible to produce accurate, daily estimates of actual E and GLAI throughout the growing season and provide farm managers with valuable field-by-field information to assist with irrigation decisions. The PROBE approach provides a means for both monitoring and predicting evaporation rates and plant biomass production, based on readily-available meteorological information. Furthermore, because of the unique model calibration technique, it requires only *periodic*, not daily, remotely-sensed information.

FUTURE PLANS: A refinement to PROBE that could improve results would be to incorporate a more sensitive leaf lifespan (L) parameter that would allow more flexibility in the model to account for leaf loss due to catastrophic events, such as insect infestation or disease. Another refinement would be to include a cotton yield prediction based on cotton GLAI or biomass estimates. The next step in the development of PROBE will be to conduct a real-time experiment in which PROBE is combined with remotely-sensed measurements to schedule irrigations of a cotton field, and results are compared with irrigations scheduled by the farm manager based on independent crop evaluations.

COOPERATORS: Dr. Dabrowska-Zielinska, Inst. of Geodesy and Cartography; Dr. Maas, Western Integrated Cropping Systems Research, Shafter, CA; Dr. Neale, Utah State Univ. Dept. of Biol. and Irrig. Eng., Logan UT.

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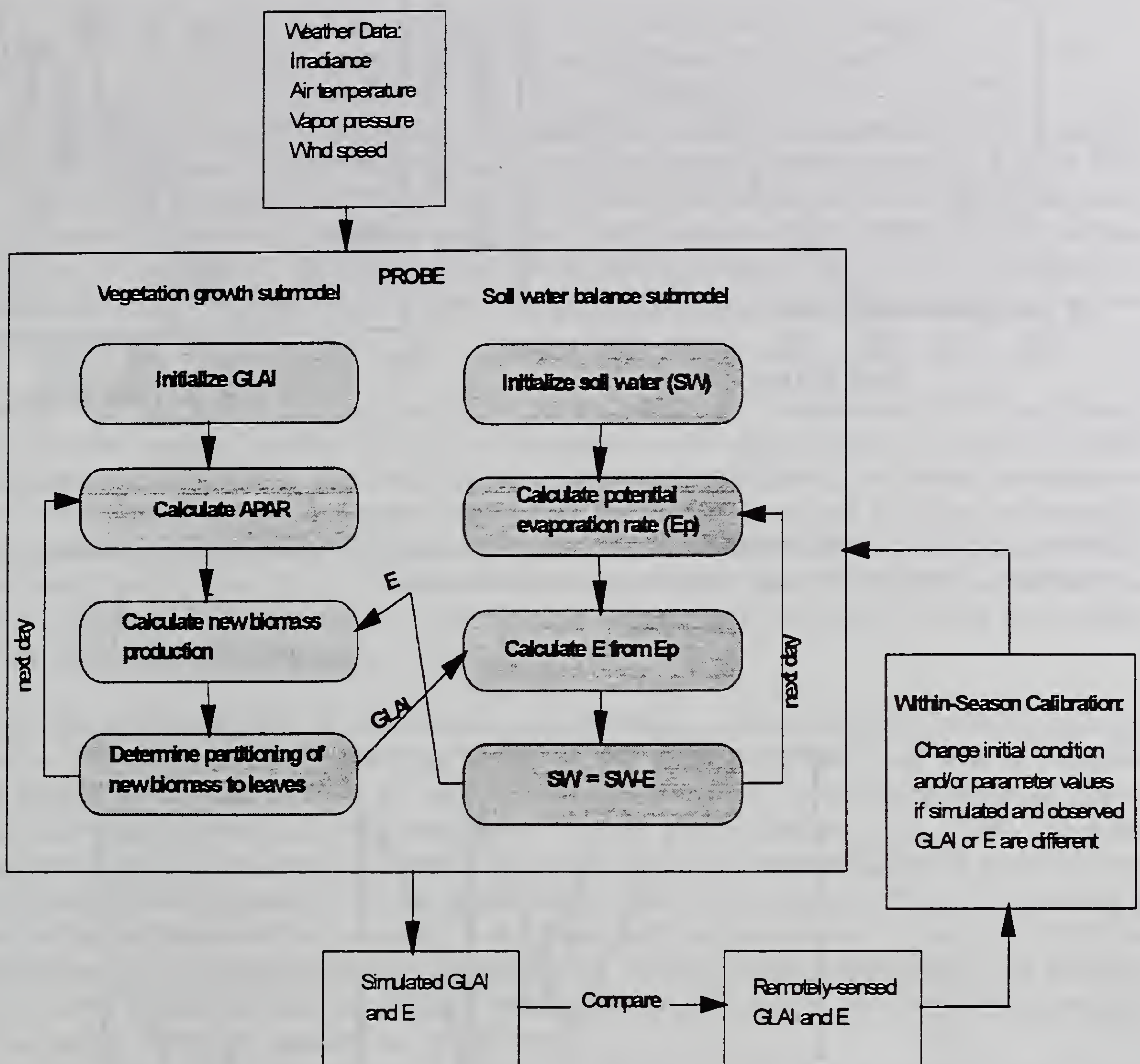

Figure 1. Diagrammatic representation of the PROtotype Biomass and Evaporation (PROBE) model.

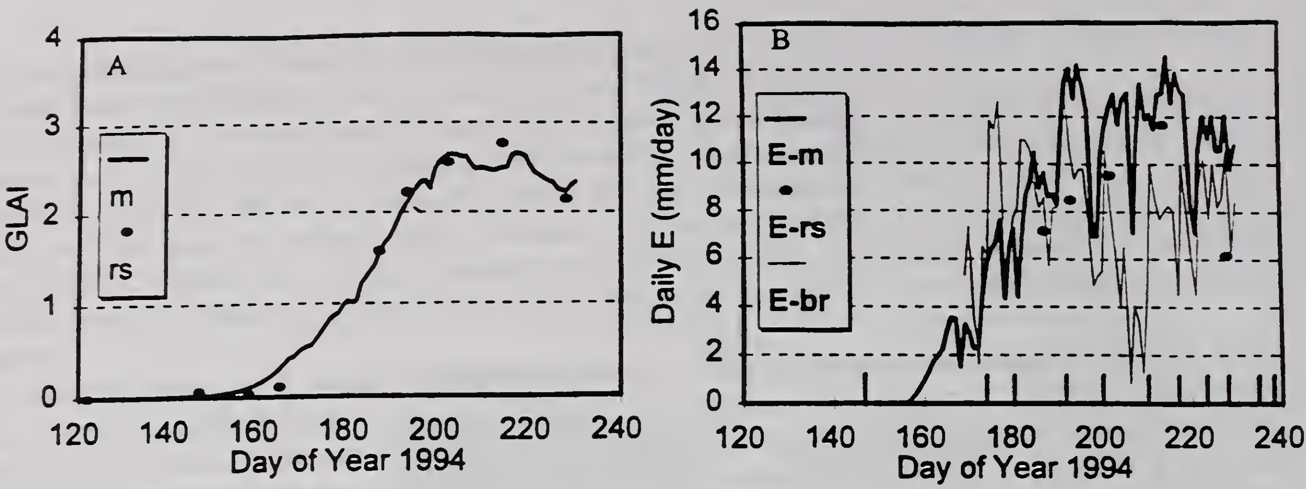

Figure 2. PROBE model results for MAC field 116-5 from DOY 120-230 (prior to severe leaf perforator infestation). Irrigation dates are designated with X-axis ticks.

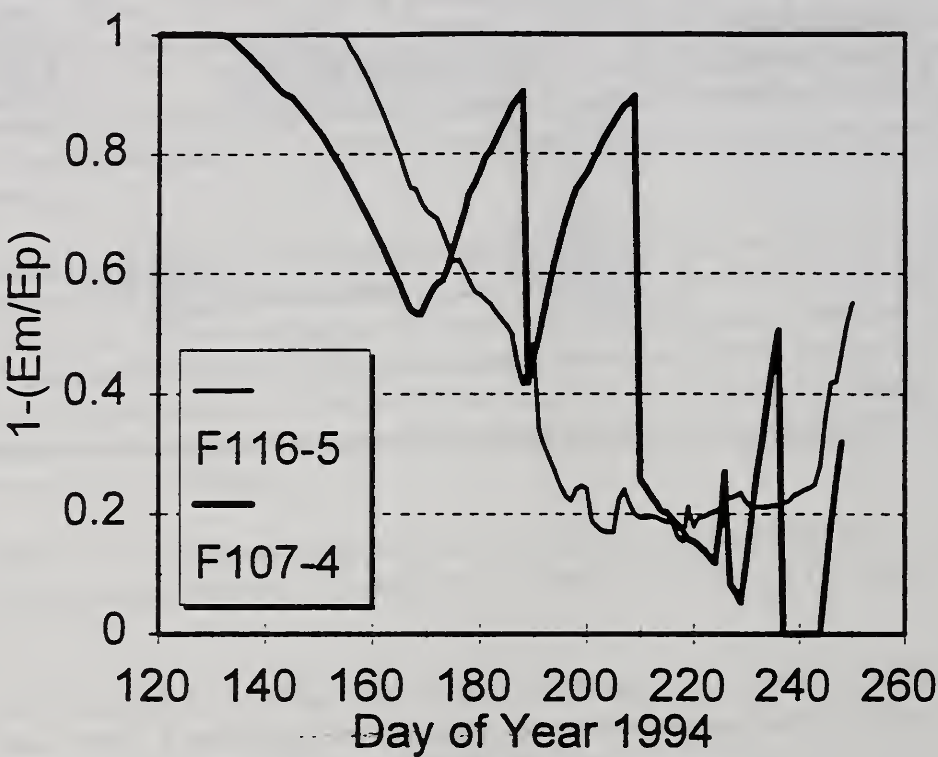

Figure 3. Illustration of (1-E_m/E_p) over time for fields 116-5 and 107-4, where E_m is PROBE-modeled evaporation rates, and E_p is the potential evaporation rate.

OPPORTUNITIES FOR REMOTE SENSING IN PRECISION FARMING APPLICATIONS

E. M. Barnes, Agricultural Engineer; M. S. Moran and T. R. Clarke,
Physical Scientists; and P. J. Pinter Jr., Research Biologist

PROBLEM: Precision farming (PF) involves the application of global positioning systems (GPS), geographic information systems (GIS), and variable rate equipment to make management decisions over very small areas. While PF does provide a means to utilize agricultural resources more efficiently, a vast amount of data is needed to maintain a farm-level GIS. Remotely sensed information has the potential to fulfill many of the input requirements for PF, as it can be acquired at a high spatial resolution over a large area in a short period of time. The objective of this study is to identify specific areas where remotely sensed data can be used to meet the information needs of PF.

APPROACH: The first step in this study was to review the information requirements of PF both through published studies and personal interviews with those involved in the PF industry. Next, a review of remote sensing literature was conducted to find existing image interpretation techniques that would provide useful information to PF. Finally, imagery and ground observations from the Multispectral Airborne Demonstration at Maricopa Agricultural Center (MADMAC, Moran et al., 1996) conducted during the 1994 summer growing season are being used to identify and demonstrate other areas where remote sensing shows potential for application to PF. Ground observations have been linked to field locations in a GIS, allowing the capability to overlay the observations on the images.

FINDINGS: Three broad areas have been defined where remotely sensed data can provide meaningful information for PF. The first area is in mapping soil properties. Currently, the typical method to describe the spatial distribution of soils in PF is by taking gridded soil samples and then applying some type of interpolation technique to increase the spatial resolution of the information (Nielsen, et al., 1995). Remotely sensed images may provide an alternative method, as spectral properties of soils have been found useful in determining their physical properties (e.g., Dalal and Henry, 1986). For example, figure 1 is an image of fallow fields in the red portion of the spectrum. Percent sand and clay determined by Post et al. (1988) are shown superimposed on the image near the sampling locations. Note how the brighter portions of the image correspond to areas of high sand content. Images of bare soils could be used to identify areas for sampling and then also used to interpolate spatially the sample results.

A second area where remote sensing can be applied in PF is to map the spatial extent of pest damage. Imagery has been used to map weed infestations to control the application of herbicides (Hanson et al., 1995). Insect and disease damage has also been detected using multispectral data (e.g., Lorenzen and Jensen, 1989). The ability to detect insect damage using multispectral imagery is illustrated in figure 2. This figure is a time series of green leaf area index (LAI) maps derived from red and near-infrared images obtained over a cotton field during the MADMAC experiment. Of the available images, the maximum leaf area index is reached on August 2. Beginning August 16, LAI decreased, which is also the time white fly and leaf perforator damage was first observed in the field. By mapping pest damage, higher levels of insecticide can be directed to the areas of infestation. In addition to reducing the amount of insecticide used, there will be less damage to beneficial insects. It should be noted that at the current level of technology, ground verification is needed to determine the cause of changes in canopy density. For example, the lower LAI bands running to the north and south correspond to irrigation treatments, not insect damage alone.

The final category where remote sensing can provide useful information to PF is in the determination of water stress. The difference between remotely sensed surface temperature and ground-based measurement of air temperature has been established as a method to detect water stress in plants (Jackson et al., 1981). Moran et al. (1994) defined a Water Deficit Index that incorporates a vegetative index to account for partial canopy conditions so that false indications of water stress due to high soil background soil temperatures are minimized. In addition to use as an irrigation scheduling aid, maps of water stress can be also used to

determine if differences in soil type within an irrigation management area have sufficient impact to warrant the creation of a new management area.

INTERPRETATION: The ability of remotely sensed data to meet a variety of information requirements for PF increases the economic viability for the application of both technologies. Additionally, if various remotely sensed data products are offered by a third party, smaller farm operators will have greater ability to practice PF.

FUTURE PLANS: The ability of remote sensing to describe variations in plant density is well documented; however, it is not currently possible to translate these variations to the impact on yield. Future research will examine the feasibility of incorporating remotely sensed estimates of evapotranspiration and LAI into existing growth models. If successful, it will be possible to use the remotely sensed information to extend the growth model's predictions spatially, and then apply the decision support aspects of these models to PF management.

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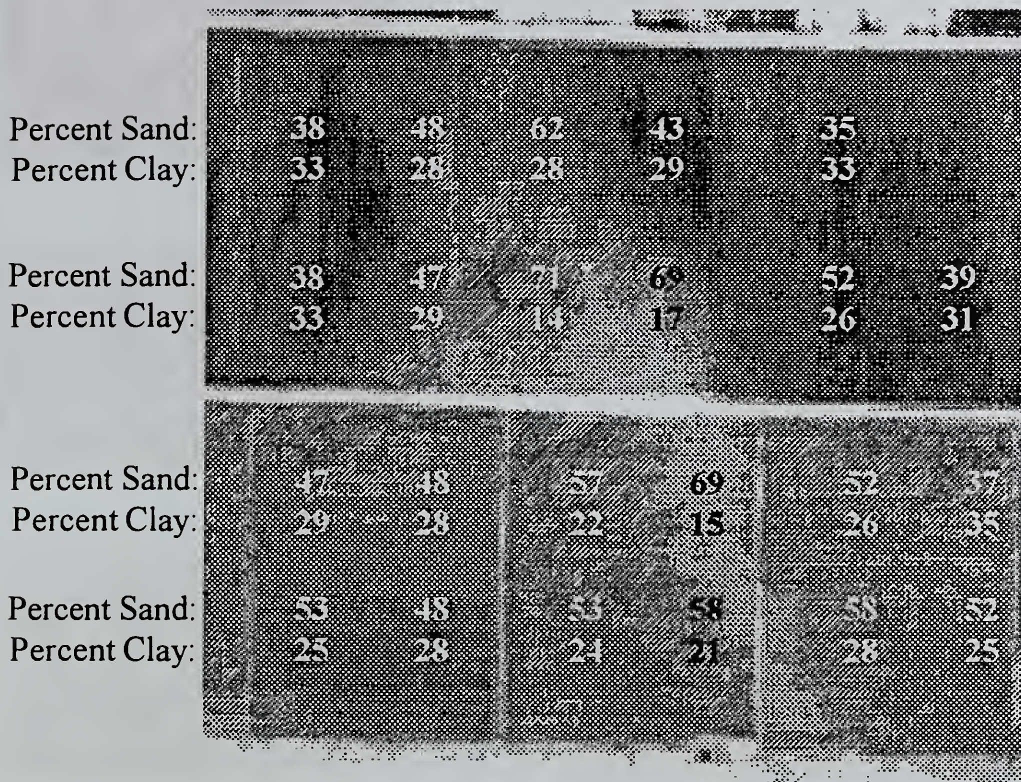

Figure 1: Gray-scale image of a bare soil field in the red portion of the spectrum with point measurements of percent sand and clay shown over the approximate sampling locations.

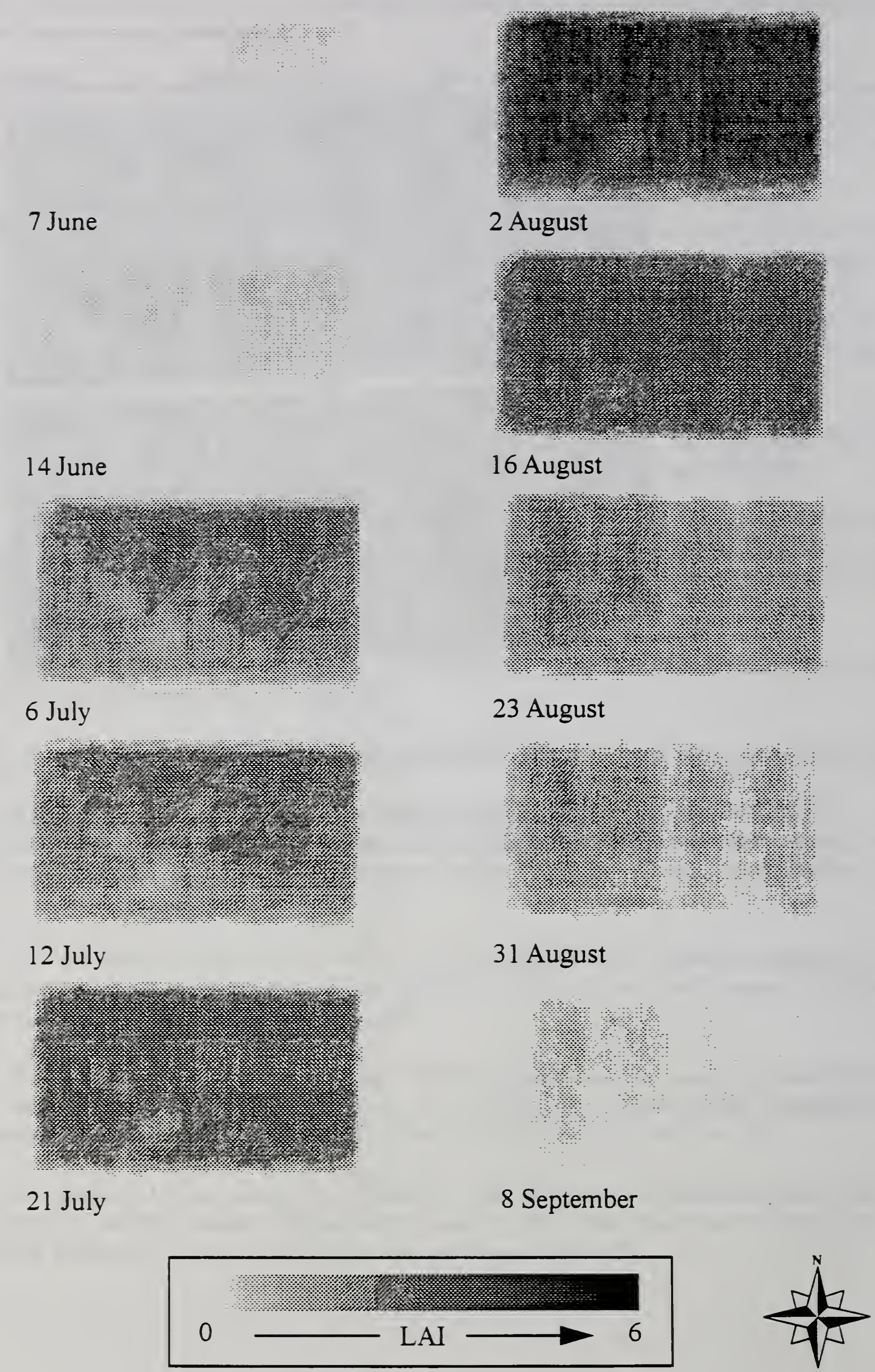

Figure 2. Remotely sensed estimates of leaf area index (LAI) over a cotton field during the 1994 MADMAC experiment.

GERMPLASM IMPROVEMENT AND CULTURAL DEVELOPMENT OF NEW INDUSTRIAL CROPS

GUAYULE LATEX EXTRACTION

F.S. Nakayama, Research Chemist; T.A. Coffelt and D.A. Dierig, Research Geneticists

PROBLEM: The U.S. Department of Agriculture has recently licensed a patent relating to the use of guayule latex for making medical products. Unfortunately, we are not at a stage of producing commercial quantities of such latex. A reliable and efficient latex extraction procedure must be developed in the overall scheme of insuring adequate latex production. Also, the extracted latex must be evaluated for biological, physical, and chemical properties and its ability to be used for making latex products.

APPROACH: Laboratory latex extraction procedures will include various methods for separating the latex from the guayule shrub. The plant materials, primarily stems, from Arizona and Texas will be processed as soon as possible after harvest. The shrub will be macerated using water-based extractants to remove the latex. Various types of emulsifying agents will be used to stabilize the solution during the extraction process. The latex will then be separated from the serum or extractant mixture by disc-type centrifuge separators or a creaming process. The latter relies completely on gravity separation and does not require any centrifugation. The raw latex will be analyzed for resin content since this is an important component controlling the properties of the latex rubber. Latex content of stems will be determined by a procedure specifically designed for this purpose (Kroeger et al., 1996).

FINDINGS: Approximately 30-50% of the total latex in the stem material could be extracted from guayule. The extracting solution with 20 mM of borate gave the highest latex yield and the lowest resin content in the raw latex compared to the other solutions (table 1). The borate buffer is used in the analysis of plant latex (Kroeger et al., 1996). The polyvinylpyrrolidone (solution 2), used in biological preparations to bind polyphenols, did not lower the resin content in the latex.

In terms of emulsifying agent, the extracting solution with Triton X-100 had the highest extraction efficiency (table 2). The Tween 80, however, had the lowest resin content in the raw latex. The cationic benzalkonium emulsifier gave the lowest latex yield. This is expected since the latex is anionic and could react with this emulsifier.

The stem latex content for the N565 line drastically decreased from 7.3% for the May 15, 1996, sample to 0.4% for the June 27, 1996, sample. This type of change has been observed in studies covering other lines (Coffelt et al., Guayule Germplasm Evaluation and Improvement, 1996 USWCL "Annual Research Report") and would have an important impact on harvest and processing dates.

Extraction efficiency was highest in the two-year-old plants from Texas (table 3). However, the total extractable latex will depend upon the biomass. The seven-year shrub had approximately three times the biomass of the younger Texas lines. The resin contents for the two lines AZ-R3 and UC101 were significantly lower than the AZ-R2 and 11605.

No correlation was present between the latex extracted (column 2, table 3) and the plant latex analyses (column 3). The plant grinding with a blender for the extraction step may not be breaking up the cells completely and not releasing all the rubber particles. However, we would expect much greater differences in extracted latex for the range of latex contents of the plants. In Kroeger's procedure, about 5 g of plant material are ground in a 1:20 solid-to-solution ratio. We use at least 200 g of material with a 1:8 solid-to-solution ratio. The rubber percentage results for our extraction procedure are similar, so the loading capacity of the extractant for latex may have been reached. More work needs to be done with a greater number of lines and types of plant materials.

INTERPRETATION: Since the physical and chemical properties of the latex obtained from the various extractant combinations have not be determined, it is premature to select the extractant that would be the best for extracting guayule latex. However, the laboratory results provide data on expected latex yields and lead to further studies on how to increase extraction efficiencies. Poor correlation between the latex content in the plant sample and the latex extracted by our method is of concern, since the plant selection and yield improvement

studies will depend primarily on rapid analysis of small amounts of plant materials so that progressive samplings on the same plant can be made. Latex can be extracted from both young and old shrubs. Thus, the older shrubs can serve as a source of latex until new plantings can be established for latex production. Also, for production purposes, it is not critical for the young shrubs to be harvested at the same time.

FUTURE PLANS: Further research will be done to increase extraction efficiency and relate extractability to latex content analysis. These include plant grinding techniques, plant-to-extractant ratios, and solution concentration. Additional work will be done to determine the relation between the extractable latex using the blender-creaming procedure and the existing plant analysis procedure. In many instances, the shrub must be transported from the harvest to the processing site. Thus, there is need to get information on the extractability and stability of the latex during this process. Shrub harvest and treatment methods must be developed to maintain latex yields. This includes a study of shrub storage before the latex extraction process. Sufficient quantities of latex will be prepared for biological, physical, and chemical characterization for evaluating the different extraction methods.

COOPERATORS: K. Cornish, USDA-ARS-PWA, Albany, CA; W. Coates, J. Hoffman, and D. Stumpf, Office of Arid Land Studies, University of Arizona; D.T. Ray, Plant Science Dept, University of Arizona, Tucson, AZ; W.W. Schloman, Jr., Department of Polymer Science, University of Akron, Akron, OH; M. Foster, Texas A&M University, Ft. Stockton, TX.

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Table 1. Effect of solution composition on latex extraction and resin content in latex (seven-year old, line N565, May 15, 1996, harvest)

Solution*	Latex, %	Extract. eff., %	Resin in raw latex, %
1	4.0 a	54.1	16.5 b
2	2.5 b	34.2	22.3 a
3	2.4 b	33.6	19.6 ab
4	2.4 b	32.9	20.8 ab

*Solution Composition

1. 20 mM borate, pH 10
2. 1% polyvinylpolypyrrolidone, pH 10
3. 0.2% Na_2SO_3, pH 10
4. 0.01% sodium lauryl sulfate, pH10

All solutions contained 0.2% Na_2SO_3 as an antioxidant; pH adjusted with ammonium hydroxide.

Table 2. Effect of emulsifiers on latex extraction and resin content in latex (seven-year old, line N565, May 15, 1996, harvest)

Solution*	Latex, %	Extract. eff., %	Resin in raw latex, %
1	2.6 a	36.3	16.4 ab
2	2.4 b	33.6	19.6 a
3	2.4 b	32.9	14.0 b
4	1.1 c	15.1	19.4 a

*Solution Composition

1. Triton X-100 (nonionic, 0.01%)
2. Sodium lauryl sulfate, (anionic, 0.01%)
3. Tween 80 (nonionic, 0.01%)
4. Benzalkonium chloride (cationic, 0.01%)

All solutions contained 0.2% Na_2SO_3 as an antioxidant. pH adjusted to 10.0 with ammonium hydroxide.

Table 3. Latex extraction for four guayule lines (two-year old from Texas, April 28, 1996, harvest)

Line	Latex,* %	Plant latex, %	Extract. eff., %	Resin in raw latex, %
AZ-R2	3.2 a	4.8 a	68.4	19.6 a
AZ-R3	3.6 a	6.0 a	60.5	16.4 b
UC101	3.2 a	10.0 a	32.7	14.0 b
11605	2.9 a	7.8 a	36.9	19.4 a

*Extraction solution consisted of 0.2% Na_2SO_3 adjusted to pH 10.

GUAYULE GERMPLASM EVALUATION AND IMPROVEMENT

T. A. Coffelt and D. A.Dierig, Research Geneticists; and F. S. Nakayama, Research Chemist

PROBLEM: Latex allergies are becoming a serious health problem, so ample sources of hypoallergenic latex need to be developed. One possible source is guayule; but higher-yielding, faster growing, and easier to establish guayule germplasm is needed for it to be successful as a commercially viable new crop. The objectives of these studies were to (1) evaluate the survival rate after first year of germplasm lines established by transplanting, (2) determine differences in plant height after first year of germplasm lines established by transplanting, (3) compare irrigation methods for use with direct seeding of guayule, (4) determine the effect of harvest date on latex content, and (5) establish plots for comparing latex contents and biomass among advanced guayule lines of different ages and plant spacings.

APPROACH: Field tests for evaluating survival rate and plant height were conducted at the Maricopa Agricultural Center (MAC) on 27 advanced germplasm lines compared to two checks (11591 and N565). Lines were transplanted on April 6, 1995, and survival ratings and plant height measurements taken on February 29, 1996. Lines were planted in a randomized complete block design with four replications. At the Marana Agricultural Research Farm, two lines (CAL-6 and CAL-7) were direct-seeded on June 6, 1996, with one bed of each irrigated by sprinkler irrigation and one bed of each irrigated by furrow irrigation until the seed were germinated and plants established. Five additional lines were also direct-seeded using sprinkler irrigation. Three lines (O16-1, G7-11, and CAL-6) transplanted at the Marana Agricultural Research Farm on May 4, 1995, have been harvested every two weeks since December 4, 1995, and evaluated for latex concentration to determine the effects of harvest date on latex production. Seven lines were transplanted at MAC on March 6, 1996, to provide plant material for comparing one- and two- year-old plants for survival rate, plant height, plant biomass, and latex content. Two lines were transplanted at spacings of 30cm and 15cm between plants for comparing the effects of plant spacing on plant height, plant biomass, and latex content.

FINDINGS: Survival rates of 19 of the 27 advanced germplasm lines at MAC were not significantly different than 11591, the best check (table 1). Two lines (G7-14 and G7-15) were significantly taller than 11591, the tallest check (table 1). More plants survived after one year in the sprinkler-irrigated beds (4.8plants/m) than in the furrow-irrigated beds (0.1plants/m). Stands for the lines varied from 1.6 to 9.8 plants per meter of row in the sprinkler-irrigated beds (table 2). Latex content in the date-of-harvest study went from about 2% in December 1995 to a maximum of about 10% in March 1996. Latex content has been dropping steadily through the summer.

INTERPRETATION: Variability within and among guayule germplasm lines was significant for survivability and plant height, thus indicating room for improvement in these traits through selection and other breeding techniques. The lines evaluated in this study should serve as excellent sources of germplasm for cultivar development in guayule. Direct seeding of guayule continued to be difficult using furrow irrigation. Experience in recent studies indicates that several factors are important for successful direct seeding of guayule. Some of these are quality seed with high germination rates, use of sprinkler irrigation for germination and stand establishment, and favorable environmental conditions following planting and emergence. More studies need to be conducted in order to better define the limits on these factors. Results from the date-of-harvest study indicate that the spring months (March and April) are probably the optimum harvest time for maximum latex production. These establishment and harvest date trials indicate that a cropping schedule in which guayule stands are established in the fall of one year and harvested about 18 months later may be best. By utilizing the faster growing lines identified in the first objective and by harvesting only the smaller branches, an annual spring harvesting scheme could be developed following the initial harvest. More work needs to be done in these areas to obtain definitive data.

FUTURE PLANS: We will continue to develop a reliable direct seeding method for stand establishment. We will also continue to evaluate germplasm lines for superior traits such as faster growth, high seed germination rates, high latex percentage, high biomass, and reduced variability among plants. We will cooperate in developing harvest schedules and methods for maximizing latex yield. These studies will all involve close cooperative work with scientists at the various locations involved in guayule research.

COOPERATORS: D. T. Ray, Plant Sciences Dept., University of Arizona, Tucson, Arizona; M. A. Foster, Texas Agricultural Experiment Station, Texas A&M University, Ft. Stockton, Texas; R. A. Backhaus, Botany Dept., Arizona State University, Tempe, Arizona; W. Coates, J. Hoffman, and D. Stumpf, Office of Arid Land Studies, University of Arizona, Tucson, Arizona; A. Estilai, Botany and Plant Sciences Dept., University of California, Riverside, California; K. Cornish, USDA-ARS-PWA-WRRC, Albany, California; W. W. Schloman, Jr., Polymer Science Dept., University of Akron, Akron, Ohio.

Table 1. Plant stands and heights on Feb. 29, 1996, of 29 guayule lines transplanted at MAC on Apr. 6, 1995.

GERMPLASM LINE	STAND (%)	PLANT HEIGHT (cm)
G7-14	99.3	40.6
P10-4	97.0	27.6
G7-15	97.0	40.5
11591	97.0	33.7
N7-11	97.0	30.0
G7-11TC	96.0	37.2
P3-11	95.5	30.6
C16-1	94.8	25.5
N9-3	94.0	29.3
N6-3	91.5	27.0
G1-10	91.3	24.0
N8-10	90.8	27.0
P10-13	90.5	30.8
P2-BK	89.3	28.3
G7-11	88.5	32.7
N12-18	87.8	27.4
P10-5	86.0	24.2
G1-16	86.0	29.1
N6-2	84.5	24.3
P11-1	84.5	24.7
N13-1	83.0	30.0
O16-1	82.3	29.2
N565	80.0	25.1
N7-5	79.8	24.0
N8-5	75.3	23.8
N7-2	75.0	31.2
N8-1	61.0	26.2
N9-4	61.0	31.9
P10-3	56.5	25.0
LSD	15.6	5.2

Table 2. Mean number of plants per meter of row for two guayule lines in sprinkler- and furrow- irrigated beds and five guayule lines in sprinkler-irrigated beds.

GERMPLASM LINE	SPRINKLER IRRIGATION	FURROW IRRIGATION
CAL-6	4.27	0.03
CAL-7	5.25	0.20
AZR-2	9.84	NA
AZR-3	5.91	NA
G7-14	1.64	NA
N9-5	1.97	NA
O16-1	1.64	NA

LESQUERELLA GERMPLASM IMPROVEMENT

D. A. Dierig, T. A. Coffelt, and A. E. Thompson (Collaborator), Research Geneticists;
and F. S. Nakayama, Research Chemist

PROBLEM: Lesquerella seed could provide U.S. industrial markets with a source of hydroxy fatty acids. In the past, these markets have been satisfied by imports of castor for many types of industrial applications. Some of these uses include paints, coatings, lubricant, and grease applications. Imports of castor oil and derivatives amount to more than 65,000 tons per year at a value exceeding $100 million per year. The unique chemical structure of the oil from Lesquerella, although similar to castor, offers distinct advantages for development of other applications as well as a partial replacement for castor oil. At present, one species native to the Southwest is being developed. Other species may also have potential as sources of hydroxy fatty acids in other geographical locations. Many species of *Lesquerella* and a closely related genus, *Physaria*, with this same type of seed-oil are becoming endangered. The germplasm base of these species needs to be expanded to preserve the diversity. The focus of our research is to collect, evaluate, and improve *Lesquerella* germplasm through plant breeding, and to develop appropriate cultural and water management practices.

APPROACH: Germplasm of *Lesquerella* and *Physaria* species were collected in Colorado, Wyoming, and Utah along with recollection of a few species in Oklahoma and Tennessee. Geographical locality information, including elevation, latitude and longitude, and associated plant species, was recorded at each location. Seed size, number of seeds per pod, growth habit, and other plant characteristics were measured. Seed-oil contents and composition were analyzed (table 1).

Seeds from some of past years' collections were field-grown at USWCL for seed increase and evaluation. When plants began to flower, screen cages were placed over individual plots and supplied with a nucleus of honey bees for pollination. Insects are necessary for seed production in Lesquerella. The cages prevented plants of the same species but different accession, from cross-pollinating. Plant growth measurements were taken throughout the season. After harvest, seeds from each accession were analyzed for oil content and composition and gum content of the seed coat.

Three recurrent populations for increased oil content, increased hydroxy fatty acid content, and oil and hydroxy fatty acid yields were repeated for the 1995-1996 season. This is the fourth cycle of these populations. Five hundred plants from each population were harvested and analyzed and compared to an unselected check population. The highest 10% of the population was chosen and planted for new recombinations and further selection.

A male sterile F2 segregating generation was planted in greenhouses at USWCL. The F2 seeds resulted from crosses between male sterile (no pollen) and male fertile (pollen) plants from 23 different plants in 50 combinations. This resulted in 50 different lines with 2,602 plants, which were scored at flowering for the male sterile trait. Some were reciprocal crosses; for example, line 1 X line 2 and the reciprocal, line 2 X line 1, to determine if the trait is passed along only through the maternal parent (cytoplasmic inheritance). Ratios of sterile and fertile plants indicate the number of genes responsible for the trait and also if it is dominant, recessive, or co-dominate.

Yellow seeded plants were greenhouse-grown at USWCL. Crosses were made between plants that produced yellow versus an orange seed coat trait. Plants producing yellow seed were selected at harvest. This trait may have an importance ~~in the cosmetic industry~~. Decoloration from the seed coat pigment present in the oil must be removed by hydrogenation. The oil from these lines may be lighter in color and eliminate this extra processing. Quality and quantity of oil and gums from these lines will be examined when sufficient quantities of these materials become available.

Seed of autofertile progeny were field-planted in caged plots with bees. These were germplasm lines selected from our industry collaborator, Mycogen Plant Sciences. The purpose was to force outcrossing between a blend of various autofertile lines with the hope of overcoming inbreeding depression. The project was sponsored by the USDA-AARC (Alternative Agriculture Research and Commercialization), but the project was terminated

early based on a decision by Mycogen. The ownership of this seed is presently under question by the AARC Board of Directors.

A procedure is being developed to produce haploid plants for use in mutation treatments. The mutagenized plants are then screened for various changes, such as in the fatty acid profile or oil content. Microspore culture is the method being developed to produce haploid plants. After haploids are mutated, chromosomes are doubled, resulting in a homozygous plant for that trait.

FINDINGS: The recurrent population for high oil content ranged between 12 and 38%. The range from the previous year was between 14 and 37%. The population mean was 26%. There was no increase from last year, possibly because of environmental effects. However, compared to the check population, oil content increased by 2.5 %, which is a 10% improvement. Analyses for fatty acid contents are not yet completed.

The ratios from the F2 generation indicated that a single nuclear gene controls male sterility in lesquerella. Male sterility results when this gene is homozygous recessive. There is more than one modifier gene (cytoplasmic) that restores fertility.

Seeds were collected from controlled crosses between plants with yellow seed coats. This seed will be increased and released in 1997.

INTERPRETATION: A major role of the USWCL research effort is to provide leadership in new germplasm collection, evaluation, genetic enhancement, and development of improved cultivars or hybrids. The germplasm collection of *Physaria* was greatly increased this year. Previously, only three accessions of two species were available in the National Plant Germplasm System (NPGS) and in our working collection. It will now be possible to increase seed and screen new accessions of both *Lesquerella* and *Physaria* for potential domestication. Most of the seed oils of *Lesquerella* analyzed were comparable to other published results. However, some had significantly lower amounts that could be attributed to immature seed. The accessions grown at USWCL this year were increased and are now available to be entered into the NPGS.

The achievement of increasing oil content through recurrent selection is encouraging. This year's results indicate that the plant's moisture content at harvest, as well as cooler temperatures, affected the analyses. If seeds are harvested too green, the oil content and fatty acid composition will be lower. Accurate comparisons between years make it necessary to have similar moisture contents each year at harvest.

Studying the inheritance of male sterility in lesquerella will allow us to control this trait. It appears relatively frequently in a population. We do not know what effect it has on seed production There is also the possibility of utilizing the trait later for hybrid seed production.

FUTURE PLANS: Evaluation of germplasm collected in previous years is planned at this location. Most species collected in the Western U.S. will be increased here. There is the possibility of species collected in the eastern U.S. to be increased and evaluated at the ARS station, Griffin, Georgia, by Robert Jarret. This will depend on obtaining outside funding for this project. A few accessions will be sent to this location for trial.

The next generation of the recurrent selection for improved oil and fatty acid content will be planted. Seed will be harvested and analyzed at this laboratory in June 1997. We plan to release a new generation from the recurrent population each year. Yellow seeded lines will be increased this season and also released.

A postdoctoral research associate, Dr. Benjamin Kaufman, has been hired and has started work to develop molecular markers for breeding.

COOPERATORS: R. L. Roth, J. M. Nelson, Univ. Arizona, Maricopa, AZ; J. H. Brown, J. D. Arquette, and R. Kleiman, International Flora Technologies, Gilbert, AZ; M. Pollard and L. Sernyk, Mycogen Plant Sciences, San Diego, CA; E. H. Erickson, USDA-ARS Carl Hayden Bee Research Laboratory, Tucson, AZ; T.Abbott and B. Phillips, USDA-ARS NCAUR, Peoria, IL.; R. C. Rollins, Harvard University, Cambridge, MA; A. Shea, C. Nordman, Natural Heritage Division, Nashville, TN.

Table 1. Results of the 1996 Germplasm Collection.

Number of species collected[1]		Number of accessions collected	Oil content (%) range	Lesquerolic acid (%) range[2]	1000 seed weight (g) range[3]
Lesquerella	24	60	5 - 35	2 - 65	0.4- 2.4
Physaria	16	67	5 - 33	20 - 54	1.5- 5.6

[1]The exact number of species collected will not be known until voucher specimens have been taxonomically verified by Reed Rollins, Harvard University. A recollection from a 1995 site was also obtained from Tennessee. Voucher specimens of plants from each site were collected and prepared for deposit at the U.S. National Arboretum Herbarium, Washington, D.C., the designated herbarium of ARS. Seed was not available at some sites, depending on the flowering stage at the time of the collection visit.

[2]When less than 2 grams of seed were available, oil content could not be accurately analyzed. Some of the lower values may be attributed to immature (green) seed weight.

[3]The reason for the lower range on the *Lesquerella* collection is that *L. auriculata* has a different predominant hydroxy fatty acid in its seed-oil. This species is higher in the C20:2-OH hydroxy fatty acid, auricolic acid.

VERNONIA GERMPLASM IMPROVEMENT

D. A. Dierig, T. A. Coffelt A. E. Thompson (Collaborator), Research Geneticists; and
F. S. Nakayama, Research Chemist

PROBLEM: Epoxidized oils are widely used for plasticizers and additives for flexible polyvinyl chloride (PVC) resins. Part of this market is satisfied by the epoxidation of either soybean or linseed oil. The composition of the seed-oil from the epoxidized product of *Vernonia galamensis* has superior and unique qualities for industrial uses. If production could be cost effective relative to soybeans, significant quantities could be utilized. One unique potential use might be as drying agents in reformulated oil-based or alkyd-resin paints. The United States presently manufactures 1230 million liters of these types of paints and varnishes annually. Drying agents currently used in them are major air pollutants, releasing volatile organic compounds (VOCs). Use of vernonia oil in these formulations would greatly reduce the VOC pollutants, and create 150,000 ha of an alternative crop for farmers to grow. *V. galamensis* is a native of Africa and flowers and produces seed under only short-day conditions. This characteristic prevented successful cultivation within the continental U.S. We successfully utilized an accession that flowered any time of the year to produce hybrids containing this trait. The objective of this research is to develop high-yielding germplasm adapted to the U.S. and evaluate vernonia's agronomic potential as a new oilseed crop.

APPROACH: Seed from plants harvested at USWCL in October 1995 were planted at the ARS facility, Puerto Rico. Eighteen selected lines, three short-day parental lines, and seven backcrossed lines were planted on December 13 and 14, 1995. Plots were seeded in eight rows, 1 meter apart, 9 meters long. Each plot had a guard row. Plants were harvested on May 7 to 9, 1996. Plants were cut with a sickle bar, baled, and combined. Seed was returned to USWCL, where it was cleaned, weighed, and analyzed for oil content. On April 22, 1996, 14 hybrid lines and a parent check line were seeded at the USWCL field. The seeding rate was four grams per 9-meter row plots. Plots were four rows wide, spaced 1 meter apart. Plants were evaluated through the season for stand, plant height, and seed retention. Measurements were taken on individual plants of different lines to determine which variables contributed the most to seed yield (table 1). At harvest, on September 12, the number of plants per row and biomass were recorded. Plants were dried in the greenhouse, and then seed was collected to determine yields. The same information was recorded for ten additional observational lines. Seed was sent for a trial planting at the Hawaii Agricultural Research Center, Aiea, Hawaii, on May 8, 1996. Two day-neutral hybrid lines, and two short-day parent lines were planted for comparisons. Seed from these plants were hand-harvested beginning in late August. Both transplanted and direct seeded plots were attempted in Safford, Arizona, on June 4, 1996. Plantings included three hybrid lines and a check.

Three lines of *Euphorbia lagascae*, selected for nonshattering, were direct seeded on May 20, 1996, at USWCL. This crop is also a source of vernolic acid and is native to Spain. Seed shattering has been one of the concerns for domesticating this crop. The planting was part of a five-location variety trial in cooperation with Oregon State University. However, poor seed quality resulted in no field germination, and the experiment was abandoned. Laboratory seed germination tests of the three lines averaged only 7%.

Seeds of the 13 original accessions from Africa were obtained for increase and growth characterization from the USDA- ARS Curator at Ames, Iowa. Two additional accessions were used from our working collection. These were germinated in the greenhouse in January 1996. All have short-day flowering requirements. Plants were transplanted to the field in February. Plant heights and number of flowers per plant were recorded.

Seed dormancy was investigated on three short-day parent lines, one month after harvest, in the laboratory with light. This was repeated at two months with a duplicate set under both light and dark conditions.

FINDINGS: The most significant finding from the 1996 planting was the selection of eight plants that appeared to retain seed longer. All but one of these selected plants were found within a single line. Measurements of the length of time plants retained their seed compared to other lines is not yet known. Seed yields, seed-oil information, and seed retention comparisons will be included in next year's report. Plots from this year were able

to survive the entire season, unlike previous years where disease devastated the field. Ridomil fungicide was applied as a soil drench in late July when plants were flowering. Symptoms included sudden wilting and girdled, stunted roots. The disease appeared to be moving with the irrigation direction.

Seed from Puerto Rico was not ready in time to be planted for the 1996 season at USWCL. This was because of the late planting in 1995. On average, we obtained 2 kg of seed from each line. Some were less because they matured before we harvested. Seed weights ranged from 2.34 to 3.36 grams per 1000 seeds. We have not obtained yield information from the Hawaii planting. Flower counts during the growing season indicated that hybrid lines were very productive. Most of the two short-day flowering parent lines remained vegetative. Direct-seeded plots at Safford, Arizona, did not germinate. This is likely because the field was irrigated with water from a well with high salt content. The transplants appeared yellow and stunted as a result of using this water. In past years, river water was used with good results. The experiment was abandoned.

Nine out of 12 accessions from five subspecies germinated, indicating poor seed quality. Only plants from *V. galamensis* ssp *galamensis* produced substantial amounts of seed because of its day-length requirement. No seed was obtained from two subspecies. Others produced a few grams of viable seed. There was large variation from the time of planting to when the first flower appeared. The weight of 1000 seeds ranged between 2 and 3 grams.

All three short-day parents germinated greater than 90% at one month, indicating no seed dormancy. Since light could have been a dormancy weakening factor, a dark treatment was added at two months after harvest. Results from this test indicated that at least one parent (A0388) may require light to break dormancy.

INTERPRETATION: The harvest at Puerto Rico supplied a large amount of seed that will be available for other laboratories to use for utilization research. This is an important area for vernonia's continued development. Three short-day flowering parent lines were increased successfully there. This will allow us to meet the needs of other researchers in the U.S. and other countries requesting seed. The method used to harvest was successful and will be used again, since it was less labor intensive.

Seed retention has been a problem for maximum harvest of seed. Since flowering is indeterminate, early matured seed heads are lost before harvest. Seed heads of plants observed for nonshattering stayed in a closed position following pollination and remained that way for a longer period of time. It is expected that the incorporation of this trait will allow a significant increase in yields since more seeds remain on the plant.

The trial planting in Hawaii was a success. Hybrid lines grew well there although the short-day parent lines did not flower. The latitude of Hawaii is further north than the African countries where vernonia originates. Hawaii could be a potential growing site because of the amount of sugar cane that has gone out of production. The experiment in Safford showed that vernonia cannot be successfully grown with salty water. In the past, we had stand establishment, but there have been weed problems. A preplant application with Treflan, at the same rate used for cotton, should be tried, provided good water quality is available.

The main objective of the subspecies study was to increase seed for future breeding and genetic studies. New seed will be sent back to the ARS Plant Introduction Station for inclusion into the National Plant Germplasm System with growth information taken during the season. An earlier planting in the greenhouse, under shorter days is necessary for better production of seed.

FUTURE PLANS: Our goals for next year are to increase and characterize the selected, nonshattering plants. Vegetative cuttings from these plants are being started in the greenhouse this fall. We hope to increase seed for spring planting and begin studying the mode of reproduction such as amounts of autofertility present. Selected lines from this year's trial will be advanced and planted next spring. We will plant vernonia early in April 1997. We also plan to use drip irrigation for planting. This will allow an easier method to apply a fungicide if necessary. Some of the subspecies that were not successfully increased will be attempted again by starting plants in December, in the greenhouse, when days are shorter.

COOPERATORS: D.T. Ray, Univ. of Arizona, Tucson; M.A. Foster, TAES, Texas A&M, Ft Stockton, TX; H.L. Bhardwaj, Virginia State Univ., Petersburg, VA; S. Torres, USDA- ARS Tropical Research Station, Mayaguez, PR; Mary Brothers, USDA-ARS North Central Plant Introduction Station, Ames, Iowa

Table 1. Regression model for seed yield and parameter estimates for independent variables. Measurements taken in the summer of 1995 on field-grown individual plants of different lines. Measurements included (1) the weight of four flower heads (capitula) per plant at the same developmental stage, (2) total number of flower heads per plant (subdivided into open, closed, ripe, and total) at four different times during the season, (3) number of filled seeds per head, (4) number of florets per head, and (5) 1000 seed weights. A total of 131 plants were measured. A multiple regression including all measured parameters, except open number of heads, had an R^2 value of 0.60. When only flower head weight and total number of flower heads were included, an R^2 of 0.52 was obtained. The highest correlation coefficient (r) was between total number of heads per plant and seed yield (r = 0.64).

R^2	Head Weight	Open Head No.	Closed Head No.	Ripe Head No.	Total Head No.	Filled Seed / Head	No. Florets / Head	1000 Seed Wt.
0.37					0.06			
0.52	15.3				0.05			
0.56					0.05		0.09	10.1
058					0.05	0.05	0.08	11.2
0.59				-0.08	0.05	0.05	0.07	9.7
059	3.6			-0.08	0.05	0.04	0.06	8.6
060	3.8		-0.01	-0.09	0.06	0.03	0.06	8.5

LABORATORY SUPPORT PROGRAMS

ELECTRONICS ENGINEERING LABORATORY

D.E. Pettit, Electronics Engineer

The electronics engineering laboratory is staffed by an electronics engineer whose duties include design, development, evaluation, and calibration of electronic prototypes in support of U.S. Water Conservation Laboratory research projects. Other responsibilities include repairing and modifying electronic equipment and advising staff scientists and engineers in the selection, purchase and upgrade of electronic equipment. Following are examples of work orders completed in 1996:

- Constructed four battery charger boxes with batteries and multiple D.C. power distribution boards containing lightning surge protection for use in the FACE experiment.

- Rewired the large valve box to SDM-CD 16 control module for the Campbell CR10 data logger control used in the FACE experiment.

- Repaired and modified a variety of equipment throughout the year, including CR21X data loggers and CR7 data loggers, various IRT hand-held guns, polycorders and polycorder cables, the convection oven, the Oxford Nuclear Magnetic Resonance Unit, anemometers, A CO_2 controller system, and A CO_2-IR analyzer unit.

COMPUTER FACILITY

T. A. Mills, Computer Specialist

The Computer Facility is staffed by one full-time computer specialist and one computer assistant. Support is provided to all Laboratory and Location Administrative Office computer equipment and applications. The facility is responsible for recommending, purchasing, installing, configuring, upgrading, and maintaining the Laboratory's Local and Wide Area Networks (LAN, WAN), computer systems, and peripherals. The LAN is composed of eight 10Base-T hubs connected to a standard Ethernet backbone providing 96 ports. This configuration provides over 120 ports to six Laboratory buildings.

A local router and a 56kbs lease line connects our Laboratory to Arizona State University. ASU provides our LAN access to the WESTNET WAN and the Internet. The Laboratory maintains a Class C block of Internet addresses operating under the domain uswcl.ars.ag.gov.

The Laboratory LAN is comprised of several operating systems and network protocols. UNIX, Netware, and Windows (various versions) are the predominant operating systems. Services such as E-Mail, print, file, remote access, and backup are provided by the LAN's eight servers. The Laboratory maintains its own Web Server, and can be accessed at www.uswcl.ars.ag.gov.

Future projects include the implementation of 100Base-T LAN segments, refining our Web Server, and enhancing our remote access and E-Mail systems.

LIBRARY AND PUBLICATIONS

L. Susan Seay, Publications Clerk

Library and publications functions, performed by one publications clerk, include maintenance of records and files for publications authored by the Laboratory Research Staff, including publications co-authored with outside researchers,[1] as well as for holdings of professional journals and other incoming media. Support includes searches for requested publications and materials for the Staff. Library holdings include approximately 1700 volumes in various scientific fields related to agriculture. Holdings of some professional journals extend back to 1959.

The U. S. Water Conservation Laboratory List of Publications, containing over 2000 entries, is maintained on PROCITE, an automated bibliographic program. The automated system provides for sorting and printing selected lists of Laboratory publications and is now accessible on LAN by the Research Staff. Publications lists and most of the publications listed therein are available on request.

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[1] Appendix A lists manuscripts published or accepted for publication from January 1 through September 30, 1996.

MACHINE SHOP

C.L. Lewis, Machinist

The machine shop, staffed by a machinist and contracted assistant, provides facilities to fabricate, assemble, modify, and replace experimental equipment in support of U.S. Water Conservation Laboratory research projects. Following are examples of work orders completed in 1996:

- A multi-layer gel cutter was designed and fabricated to facilitate research for genetic markers for trait selection of vernonia and lesquerella. The cutter consists of a frame fabricated from 6061T6 aluminum. The frame top is 1/2" x 1 3/4" x 8", and the sides are 1/2" x 1 3/4" x 6". Seven holes .015" in diameter and spaced .100" apart were drilled in each side. Steel wire .008" in diameter is threaded through opposite holes and secured at the desired tension with 6-32 cap screws. The cutter enables the operator to slice six sample sheets at one time from a gel sample.

- Modifications were made to existing plumbing in the Hydraulics Laboratory for a variety of closed-pipe flow measurement studies. A manifold piece was fabricated from 16" OD pipe 48" long. Two ports were torch cut into the pipe, and 12" OD flanged sleeves were welded into the ports. This manifold allows two 12" PVC pipes to be connected to existing plumbing and allows enough water to be delivered to the head tank of a 36" concrete pipe.

- Mounting brackets for gate position sensors were designed, fabricated, and installed. The sensors were developed as part of a Cooperative Research and Development Agreement between USWCL and Automata Inc., of Grass Valley, California. The mounting brackets consisted of a back plate and riser clamp. The back plates were made from 1000 series steel 1/4" x 3" x 48" and were machined to fit the assembly bracket. The riser clamps were fabricated from 6061T6 aluminum and were milled to .002" tolerance. The back plates were welded to the irrigation gates and the assembly with riser clamps was attached with 1/4-20 stainless steel bolts.

- A root core tube extractor was designed and fabricated to facilitate gathering of data for the FACE project. The extractor is a 5-foot tripod with offset pulley and a two-stage 3200-lb winch with 1/4" steel cable. The tripod is constructed from 1" 6061T6 aluminum tubing for the legs and 1" 6061T6 aluminum plate for the top. The legs are held 30" apart during use and fold for transportation. The offset pully, allowing the winch cable to run through the center of the tripod head, is fabricated from 1000 series steel with pressed bearings for turning. The two-stage 3200-lb winch is welded to a tripod leg 12" from the top plate.

APPENDIX A

APPENDIX A

Manuscripts Published or Accepted for Publication from January 1 through September 30, 1996

ALLEN, R.G., C.M. BURT, A.J. CLEMMENS, and L.S. WILLARDSON. 1996. Water conservation definitions from a hydrologic viewpoint. Unpaginated (CD-ROM). IN: Proc. ASCE North American Water and Environ. Congress '96, Anaheim, CA, 24-28 June 1996. WCL# 1919.[1]

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